ABSTRACT

Title of Dissertation:	EXPLORING THE DIMENSIONS OF GENDER AND STUDENT EPISTEMOLOGIES IN A REFORMED LEARNER-CENTERED ORGANISMAL BIOLOGY COURSE: A MIXED METHODS APPROACH
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Gender and student epistemology play a role in how students interact with STEM content and knowledge development in the classroom and may influence the retention of women in the sciences. Reform agencies have called for changes to the undergraduate biology curriculum to produce students with high level quantitative and critical thinking skills. As educators seek to reform college biology courses to align with policy maker recommendations, it remains important to consider how these dimensions influence student learning of reformed content and pedagogy. This mixed methods study explored the dimensions of gender and epistemology as they related to student learning in a reformed learner-centered organismal biology course at a large east coast university. Pre-test and post-test epistemological survey results and qualitative interview data collected over two semesters by Hall (2013) were analyzed. The results indicated

that there was no significant relationship between gender and student epistemologies at pre-test or post-test on the MBEX I instrument or in 3 of the 4 epistemological clusters. Both women and men experienced significant positive shifts on the instrument overall and in two clusters of the survey instrument. Specifically, women and men became more sophisticated in their view of the structure of biological sciences knowledge as composed of principles, and how biology knowledge should be constructed rather than memorized. Qualitative findings, however, suggested that gender and level of epistemological sophistication played a role in how women and men experienced the reformed content and pedagogy in the course. Specifically, women expressed resistance to the inclusion of physical science content in the course, while most men expressed receptivity.

This study is unique in that it explored the interplay between gender and epistemology as it related to course content and pedagogical reform. Through integration of the quantitative results and qualitative findings, the study concluded that the reformed learner-centered course was successful at creating more epistemologically sophisticated men and women who viewed biological knowledge as principles-based and developed a belief that biological knowledge is a process of knowledge construction. The results also suggested that women had a more favorable response to the active learning pedagogy. Gender may have created a potential resistance to the inclusion of other disciplinary perspectives and content in the course. The results and findings add to the higher education curriculum reform and instruction literature by providing some insight into how student epistemology and gender may influence faculty efforts to develop courses that align with national reform efforts.

EXPLORING THE DIMENSIONS OF GENDER AND STUDENT EPISTEMOLOGIES IN A REFORMED LEARNER-CENTERED ORGANISMAL BIOLOGY COURSE: A MIXED METHODS APPROACH

by

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Dedication

I dedicate this dissertation to my husband, Nick, and our children, Mikhali, Alex, and Eva, who reminded me that teaching people to reach their goals is easier when you reach your own goals first. Thank you for bearing with me during this long journey and allowing me to take dedicated time away from all of you to write the final chapters. Nick – you have been my rock for the past thirty years and have enjoyed all legs of my educational journey – high school, bachelors, masters, and doctorate. This final chapter of my education would never have been complete without your belief that I could do this!

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Chapter 1: Introduction

Advances in the life sciences will create solutions to complex societal problems, such as limited food supply, lack of environmental resiliency, energy inefficiency, and threats to individual health and wellness. New fields emerging within the discipline are increasingly interdisciplinary, quantitative, and draw on other science, technology, engineering, and math (STEM) disciplines (National Research Council [NRC], 2009). The biologist of the future will require strong computational skills, the ability to integrate information from multiple disciplinary perspectives, and skill in effectively communicating and collaborating on multi-disciplinary teams (American Association for the Advancement of Science [AAAS], 2011, 2015). The NRC (2009) described this individual as "not a scientist who knows a little bit about a lot of disciplines, but a scientist with deep knowledge in one discipline and basic fluency in several" (p. 20). These reform minded agencies suggested that institutions move away from large lecture content delivery and recommended the inclusion of interdisciplinary content and active learning approaches as a vehicle to produce the type of scientist needed in the future.

Despite these recommendations the large lecture format prevails at many higher education institutions. Evidence suggested that this learning environment impacted "students' decisions to abandon STEM degree programs" (Scott, McNair, Lucas, & Land, 2017, p. 93), contributed to the ongoing gender imbalance in the STEM workforce (Dasgupta & Stout, 2014), and produced students with naïve epistemologies for learning in the sciences (Hall, 2013) who are ill-equipped to handle the complex scientific problems of the future.

When students enter the biological sciences classroom, they bring prior conceptual knowledge (Trujillo & Tanner, 2014) and certain epistemologies, as well as beliefs about the nature of knowledge and knowing (Hofer, 2000, 2004), that may interact with their expectations of the classroom environment (Hall, 2013), and influence learning outcomes (Lising & Elby, 2005; Ding & Mollohan, 2015; Mollohan, 2015; Schommer-Aikins & Duell, 2013). The goal of undergraduate STEM education is to produce students with a deeper understanding of scientific principles whose beliefs about the nature of knowledge and knowing are more like experts in the discipline. Science experts understand that the nature of scientific knowledge is not fixed; rather, it is unsettled with opportunities for theoretical evolution as new findings emerge. When learning in the sciences, experts know that scientific knowledge is not a collection of isolated facts to be memorized with little or no connection to the real world or other scientific disciplines.

Studies have demonstrated that the traditional lecture-based approach to teaching in the sciences negatively impacts student epistemologies, resulting in students with less sophisticated views of science and science learning (Hall, 2013; Hammer & Elby, 2003; Hoskins, Lopatto, & Stevens, 2011; Redish, Saul, & Steinberg, 1998). Dai and Cromley (2014) concluded further that the negative shift of student epistemologies that can occur in traditional lecture-based classrooms may influence the STEM pipeline. Feminist theorists suggest further that this pedagogical approach creates a learning environment that fails to foster a sense of belonging for women (Dasgupta & Stout, 2014) and impacts their self-concept for learning in the sciences (Seymour & Hewitt, 1997).

To date, close to half of all current STEM majors will not persist to graduation in their chosen field (United States Department of Education, National Center for Educational Statistics [NCES], 2017). Of those students who do graduate in a STEM discipline less than thirty percent are women, representing “untapped human capital that, if leveraged, could enhance the science technology engineering and math (STEM) workforce” (Dasgupta & Stout, 2014, p. 21). While the gender gap in biology is smaller than in other STEM disciplines, there remains a void of women in the biological sciences at the higher levels (Hill, Corbett, & St. Rose, 2010) that suggests an ongoing lack of gender parity in the discipline. According to Nielsen et al. (2017), “When it comes to science collaborations, there’s ample data to suggest that gender diversity pays a substantial research and productivity dividend” (p. 1740). To create sustainable solutions to the problems facing the future global marketplace, women have the potential to make a significant impact.

As faculty reform college-level biology courses in response to policy maker recommendations, it remains important to understand better how women and men experience these changes and explore how their epistemologies for learning in the discipline may shape that experience. Muis and Gierus (2013) contended that “epistemological thinking matters” (p. 408) to curriculum reform initiatives. This dissertation explored the dimensions of gender and student epistemology in the experiences of women and men in a reformed, learner-centered organismal biology course taught at a large, east coast institution. The instructors of this large lecture course included small group, guided active engagement activities (GAEs) that incorporated the content of math, physics, and chemistry. By creating activities that required students to reason critically and engage in problem-solving, the faculty members systematically addressed epistemologically naïve conceptions in order to develop the sophisticated thinking beneficial to the 21st century biologist. While the GAEs were not specifically designed with the intent of reducing the gender gap in the sciences, this type of learner-centered classroom environment aligned with recommendations for producing a gender-neutral environment.

Statement of Problem

Critics of undergraduate biology curricula and pedagogy contended that the popular teacher-centered, large lecture-based environment is not sufficient to produce a diverse workforce with the type of critical thinking and epistemological sophistication needed to lead scientific development in the 21st century (Hill et al., 2010). Evidence suggested that the traditional lecture-based approach emphasized passive learning and rote memorization over critical thinking (Knight & Wood, 2005), created a culture of competition that contributed to women feeling unworthy of producing successful outcomes in STEM courses (Schubert & Bowker, 2017), and impacted the ongoing gender disparity in the STEM pipeline (Wilson & Kittleson, 2013). Additionally, students failed to comprehend core biological science concepts after instruction (Agorram et al., 2010; Marbach-Ad & Stavy, 2000; Smith & Knight, 2012), had difficulty integrating complex concepts with their existing science knowledge (Newman, Catavero, & Wright, 2012), and became less sophisticated in their epistemologies (Hall, 2013) when taught in this format.

In transforming biology courses to meet the needs of the future global marketplace, researchers encouraged faculty to attend not only to producing enhanced cognitive outcomes, but also to influencing student epistemologies positively (AAAS, 2011; Hall, 2013; Hammer, Elby, Scherr, & Redish, 2005). Hill et al. (2010) suggested that such a transformation might promote the retention of diverse STEM students in the profession. There is a robust body of research that confirmed learner-centered instructional contexts can promote positive cognitive learning outcomes, such as conceptual understanding and critical thinking (Marbach-Ad & Stavy, 2000; Smith & Knight, 2012), but very few studies have examined the relationships between these pedagogical contexts, student epistemological beliefs, and student learning in the sciences (Hall, 2013; Hammer et al., 2005). Even fewer studies investigated the role gender plays in how student epistemologies are manifested in a learner-centered biological sciences course in relation to the student experience. By gaining a more robust understanding of the interplay between epistemology, gender, and pedagogical context, this dissertation contributes to the gap in the higher education literature. As a result, this study adds to the epistemological research base in biology education, and provides a more nuanced understanding of how women and men experience a reformed biology course.

Theoretical Perspectives on Science Learning and Epistemology

According to Kelly, McDonald, and Wickman (2012), "Epistemology is a branch of philosophy that investigates the origins, scope, nature, and limitations of knowledge" (p. 281). To frame their work, they described three epistemological perspectives that provide a foundation and lens for understanding learning in the scientific disciplines. These three lenses are referred to as the disciplinary, personal ways of knowing, and social practices perspectives. While these epistemological perspectives are presented here as distinct frameworks, there are common tenets amongst the three. In this study, I acknowledge that all three perspectives may influence how students learn in the reformed, learner-centered classroom. These perspectives are introduced here and revisited in more detail in Chapter Two.

Disciplinary Perspective

The disciplinary perspective was built on the work of historians and philosophers of science (Dewey & Hickman, 2007; Kuhn, 1977). Proponents of the disciplinary perspective maintained that there are characteristics of professional scientists and practices conducted by these scientists that are different than those enacted by other professionals. The disciplinary perspective of knowing, values the relationship between the nature of science (NOS) and the student's view of the NOS. Student learning from this perspective is the "understanding that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (influenced by scientists' background and experiences), partly the product of human imagination and creativity (involves invention of explanations), socially and culturally embedded, the distinctions between observations and inferences (scientific knowledge is partly a function of each), and the relationships between scientific theories and laws" (Khishfe & Lederman, 2007, p. 941).

Following this line of reasoning, the job of the science educator is to teach students to understand the norms and engage in practices that are the hallmark of the scientific profession (Russ, 2014). This sets up a continuum of learning where students are viewed as "novices" and professional scientists are viewed as "experts". Russ (2014) suggested there are potential risks in framing science learning from such a "unitary, singular" construct. She argued that students need to negotiate scientific content and construct knowledge within a context of his/her past experiences and knowledge base at a moment in time. To this end, she acknowledged that individuals have a personal way of knowing that interacts with epistemology of science as he/she constructs understanding.

Personal Ways of Knowing

The personal ways of knowing perspective emerged from William Perry's (1970) work on college student learning. Perry described student learning as being inherently developmental and occurring on a continuum. During the learning process, students move from the naïve stance that knowledge is concrete, and teachers are the authority, delivering facts to students to be memorized, to the more sophisticated understanding that learning requires integration and reflection. Researchers who view science learning from this perspective focused on “ideas individuals hold about knowledge and knowing” (p. 353).

Hammer et al. (2005) contended this developmental continuum reflects an idea of “knowledge as stuff” (p. 112). The knowledge in this context is viewed as being correct or incorrect with expert views being stable constructions occurring in the same way in every domain. However, Elby and Hammer (2001) suggested that epistemologies are more contextual, finer grained resources that have a social base.

Social Practices

The social practices perspective “considers the social practices that determine what counts as knowledge in local, contingent contexts” (Kelly et al., 2012, p. 282). Theorists aligning with the third perspective posited that students have “multiple epistemological resources for understanding the source of knowledge and these different resources get activated in different contexts” (Hammer et al., 2005, p. 97). The accurate activation of these resources in new combinations plays a role in learning and teaching students to “become deliberative and reflective about their own learning process” (Hammer et al., 2005, p. 115). Dufresne, Mestre, Thaden-Koch, Grace, and Leonard (2005) proposed, “Learning can be characterized as a change in the state of a brain that would produce a different pattern of activation/application of knowledge in future responses to a particular context” (p. 190). To maximize student learning, it is important not only for faculty members to provide learner-centered approaches to pedagogy, but also to examine how a student’s epistemology shapes his/her learning in undergraduate biological sciences courses.

Lising and Elby (2005) reported that a “student’s personal epistemological stance — her ideas about knowledge and learning — can have a direct, causal influence on learning” (p. 372). Hammer et al. (2005) found that “transfer of epistemology led to further transfer at the level of conceptual understanding” (p. 111) in an undergraduate physics course. In this study, students with a less sophisticated epistemology for learning in physics struggled with conceptual understanding when faculty attended to the student epistemologies, in addition to conceptual understanding. In the first study of its kind in the biological sciences, Hall (2013) examined a reformed organismal biology course and explored how pedagogy affected shifts in student epistemologies. Her results indicated that transforming the content of the course to include connected, interdisciplinary approaches alone was not sufficient to produce epistemological shifts to a more sophisticated view. In fact, students in these reformed courses who were taught using the traditional, teacher-centered lecture approach had a less sophisticated view of biology than they had at the beginning of the semester after one semester of instruction. This negative shift of epistemologies occurred despite alignment of the curriculum to “New Biology” needs. On the other hand, students who experienced a reformed biology course taught with the inclusion of learner-centered, active learning activities had more sophisticated views of biology at the end of one semester of instruction, suggesting that learner-centered pedagogy produced epistemologically more sophisticated biology students (Hall, 2013).

Furthering the personal ways of knowing perspective, feminist theorists suggested that knowledge construction in the sciences is a personal process that occurs within a social context (Arner-Welsh, 2010), and the very nature of science is inherently authoritative and masculine. Women develop in a complex social system with experiences viewed through a gendered lens. Their experiences influence how women construct and make meaning of knowledge. Women learning in biology are often navigating their own knowledge construction in the context of the social norms around them. Arner-Welsh (2010) suggested, “If girls are drawing on specific epistemologies that are interfering with the performance of or interest in science, then studying the concrete ways in which girls are utilizing these epistemologies will enrich our understanding” (Arner-Welsh, 2010, p. 3).

The relationship between science knowledge, epistemology, and gender is inherently complex. It was not the goal of this researcher to narrow this study to causal relationships between gender and outcomes or retention of women in the sciences; rather, it was to explore how epistemology and gender manifested in a learner-centered science classroom so that we can better inform future efforts of pedagogical change. Drawing on the work of Russ (2014), the focus here was on the norms, values, interactions, and context the individual learner brought to the construction of knowledge in the science classroom.

Kelly et al. (2012) suggested that researchers interested in epistemology and science learning “draw from and are informed across perspectives. These perspectives may be mutually supported, or in some cases offer divergent directions for research” (p. 288). In this study, I acknowledged that women construct knowledge in relation to their personal experiences in a social setting, and that this learning takes place within the context of a scientific discipline. As such, the theoretical framework for this study was informed by all three epistemological perspectives presented previously.

Theoretical Perspectives on Science Instruction

Learner-centered instructional strategies emerged from constructivism. Constructivists asserted that students construct knowledge as part of an active social process (Mayer, 2004). In this model, the task of the educator is to facilitate this knowledge construction rather than deliver content to a passive recipient. Active learning instructional activities increase performance of students in the STEM disciplines and provide opportunities to improve diversity within the disciplines (Freeman et al., 2014). Active learning is a pedagogy that "engages students in the process of learning through activities and/or discussion in class, as opposed to listening passively to an expert. It emphasizes higher-order thinking and often involves group work" (Freeman et al., 2014, p. 8414) and authentic problem-solving (Gardner & Belland, 2011). While there is a diverse set of instructional strategies that fall under the active learning umbrella, the small-group active-engagement exercises (GAEs) utilized in the learner-centered classroom explored in this study were grounded in two popular approaches to active learning: problem-centered and cooperative learning. I introduce these two approaches briefly in the next section of this chapter, and at length in Chapter Two.

Problem-Centered Instruction

Case-based instruction (CBI) and problem-based learning (PBL) are two examples of the problem-centered instructional approach. Overall, these are methods of instruction that use a problem or case to facilitate student learning. Baeten, Dochy, and Struyven (2012) characterized the case method of instruction as a collaborative and facilitated process in which students actively participate in the construction of knowledge around an authentic task. This approach was popularized by professional school faculty in order to provide students with a real-world context for lecture content (Merseth, 1991). Not only does the active involvement of students with case problems provide this context for learning, but instructors also require that students think critically about a concept and engage in decision-making about case-related questions. This decision-making process encourages students to process information actively by applying their knowledge from one context to another to develop a more meaningful understanding of course content (Gallucci, 2006). Cases can also give students an opportunity to identify their gaps in conceptual understanding and engage in collaborative group discussions (Gardner & Belland, 2011).

Cases are narratives that pose complex problems for students to solve. The role of the instructor in this model is one of facilitator, not lecturer (Beijaard, Verloop, & Vermunt, 2000). The types of cases vary by discipline but usually involve problem-solving and decision-making processes. In the sciences, students can be presented with a dilemma and asked to work collaboratively to find a solution (Gardner & Belland, 2011) or work in a more self-directed manner, as often seen with some applications of PBL (Savery, 2006). Popular in medical schools, PBL models start instruction with a case, and students develop understanding of content while seeking to solve the patient's problem.

Inquiry-based learning is another case method of instruction that is like problem-based learning. Savery (2006) said the "primary difference between PBL and inquiry-based learning relates to the role of the tutor. The tutor in an inquiry-based approach is both a facilitator of learning (encouraging/expecting higher-order thinking) and a provider of information” (p. 16). In a PBL approach, the tutor is only there to facilitate the process.

Researchers have demonstrated that the problem-centered approach is successful at improving critical thinking (Cloud-Hansen, Kuehner, Tong, Miller, & Handelsman, 2008) and scientific reasoning skills (Herreid, 2007), encouraging student engagement (Bergland et al., 2012), fostering deep approaches to learning (Baeten, Kyndt, Struyven, & Dochy, 2010), and increasing conceptual understanding (Yadav, Vinh, Shaver, Meckl, & Firebaugh, 2014). By engaging in an authentic problem-solving activity, students learned to identify important information (Smith et al., 2005), developed analytical and interpretative skills (Allchin, 2013), and perceived that their understanding of biology content was improved (Wolter, Lundeberg, Kang, & Herreid, 2011). Many of these studies were comparative in nature, comparing traditional lecture practices to problem-centered approaches.

Pai et al. (2010) compared a case-based approach to a traditional lecture approach on three topics — ecology, evolution, and biodiversity — in an introductory biology course at Spelman College. They used an end of the semester survey and a twenty-two-question college-administered evaluation to obtain information on student perception of learning with cases and compared pre-test/post-test data to explore learning gains. The pre-test/post-test was a twenty-question test designed by the course instructor to address understanding of basic concepts in ecology, evolution, and biodiversity. While the authors concluded that the case-based approach was effective in teaching these concepts, the evaluation tool did not address the specifics taught by the cases and may not be reflective of learning gains. They also examined grades on case study work as a measure of learning gains but found inconclusive results. The authors concluded that students perceived that they learned more with the case-based approach than with traditional lecture. In addition to improving learning outcomes, these problem-centered approaches have documented effectiveness in shifting student epistemologies to a more sophisticated view of biology and the nature of scientific knowledge (Hall, 2013).

Cooperative Learning

Adkinson (2007) suggested cooperative learning was "designed for students to work together toward a shared goal" (p. 40). Cooperative learning teams often combine the problem-solving approaches discussed in the previous section. Luckie et al. (2013) suggested, "College faculty can use cooperative learning to increase student achievement and help ensure that their students actively create their own knowledge" (p. 197). According to Johnson and Johnson (2009), for cooperative learning teams to be effective, students need to feel connected to the group and the project goal. They also need to have a sense of their own accountability to the group process. When instructors effectively incorporate cooperative learning in the classrooms, they see improved student achievement and attitudes (Luckie et al., 2013) and positive changes in student epistemologies in learner-centered classrooms in the biological sciences (Hall, 2013). Much of the research conducted on cooperative learning environments compared traditional lecture practices to cooperative learning contexts and consistently reported positive outcomes for students engaged in cooperative learning groups. Hewitt and Seymour (1991) contended that the cooperative learning environment is less competitive than the traditional lecture classroom and thus appeals more to women.

Learner-centered Biological Science Classrooms

National reform initiatives encourage undergraduate biological science instructors to incorporate these problem-centered and cooperative learning strategies into their classrooms (NRC, 2009). Building on these recommendations, faculty at a large research university redesigned their organismal biology course. Organismal biology is a third-semester course designed for biological science majors that emphasizes the underlying principles of the diversity of life. While attention to pedagogy and content are important parts of the reform puzzle, it is also understood that reformers must also be attentive to how students view the nature of biological science knowledge and what it means to learn in this discipline. Lising and Elby (2005) found that students with a naïve epistemology for learning physics had difficulty understanding content which influenced intended learning outcomes. Interestingly, studies from both physics and biology documented that traditional lecture instruction lead to negative shifts in student epistemologies from a more sophisticated to a less sophisticated view of what it means to learn in these disciplines (Hall, 2013; Redish et al., 1998). Dai and Cromley (2014) suggested that this negative shift in student epistemologies might play a role in retention in STEM disciplines as students also become less confident in their abilities to perform in a STEM discipline.

Purpose and Design of the Study

Employing a mixed methods design to analyze secondary data (Creswell, & Creswell, 2018), I sought to develop a more robust understanding of how the dimensions of gender and epistemology influenced the experiences of men and women in a reformed organismal biology classroom. In this study, two semesters of Maryland Biology Expectations (MBEX I) Survey outcome data (Hall, 2013) were used to explore the relationship between student epistemologies and gender across four epistemological dimensions in the reformed, learner-centered pedagogical context at pre-test and post-test. I also used qualitative thematic analysis of videotaped student interviews collected by Hall (2013) to develop a more robust understanding of how gender and student epistemologies were manifested in the learner-centered course. The integration of both quantitative and qualitative outcomes allowed me to develop deeper understanding of the influence of gender and epistemologies on student experiences in the reformed course. The original data were collected by Kristi Lynn under the direction of Todd J. Cooke, PhD (PI) and Edward F. Redish, PhD (Co-PI) as part of the *The Physics of Life: Interdisciplinary Education at the Introductory Level* Project funded by a NSF Division of Undergraduate Education Grant # 0919816.

Research Questions

This study explored the dimensions of gender and student epistemologies in a reformed learner-centered organismal biology course and addressed the following research questions:

1. What is the relationship between gender and student epistemologies prior to instruction in a reformed learner-centered organismal biology course?
2. What is the relationship between gender and student epistemologies after one semester of instruction in a reformed learner-centered organismal biology course?
3. What are the gender differences in the change of student epistemologies from pre-test to post-test in a reformed learner-centered organismal biology course?
4. How do men and women describe their learning experiences in a reformed learner-centered organismal biology course?

Significance of the Study

The biologists of the future must make reasoned and thoughtful decisions regarding potential implications and impacts of advances within the life sciences. They must come from diverse backgrounds and have a clear understanding of biological systems, strong computational skills, the ability to make interdisciplinary connections, and work effectively on collaborative teams (NRC, 2009). To produce this biologist, faculty need to transform courses in a manner that improves gender equity within the life sciences (Eddy, Brownell, & Wenderoth, 2014), while also enhancing conceptual and epistemological outcomes of instruction (Andrews et al., 2012; Kilic & Saglam, 2009; Klymkowsky, Gheen, & Garvin-Doxas, 2007; Hall, 2013; Smith et al., 2005; Smith & Knight, 2012). Critics maintain that the teacher-centered, lecture-driven instructional approach popular in biology courses at most undergraduate institutions is insufficient in meeting these objectives (Baxter, 2010;

Dogru-Atay & Tekkaya, 2008; Dougherty, 2009; Lindemann, Britton, & Zundl, 2016; Yilmaz, Tekkaya, & Sungur, 2010). Learner-centered approaches to teaching biology are gaining popularity, but little research is available on the how gender and epistemologies may influence student experiences in these reformed learning environments. This study adds to the literature on learner-centered pedagogies in biological sciences education by exploring the dimensions of gender and student epistemology for science learning in a learner-centered organismal biology course.

Personal Position Statement

As a woman who majored and teaches in the biological sciences, it is important to share my viewpoint with the readers of this dissertation. Biology is a discipline that shares a foundation with physics and chemistry. I am committed to the interdisciplinary nature of science and to the idea that meaningful learning occurs when students have the opportunity to engage in active construction of knowledge. As early as high school, I recognized that I had a deep and abiding fascination with science, particularly Biology. While science was not necessarily my best subject, it was the subject that fascinated me the most. As an undergraduate student, I chose to major in Zoology at a large east coast research university. My first two years at the university were standard fare where courses were conducted in large lecture halls with the "sage on stage" providing content for me to note and memorize later. On the first day of class my freshmen year, I recall my professor asking the over three hundred students in the course to "Look to the left and look to the right. Two thirds of you will not be biological sciences majors by next semester." As a young aspiring biologist, that statement did little to inspire my ability to be successful in the discipline. I still cringe when I hear such ridiculous sentiments shared with students some thirty years later.

As an undergraduate, I studied extensively to earn good grades in my courses. I took comprehensive notes, read the textbook diligently, practiced questions, and made note cards that I memorized to be successful on the tests. I saw biology as distinct from chemistry, physics, and math and suffered through those required courses for my major. I never made an attempt to synthesize the content or make connections to other disciplines or my long-term career goals. As I moved into smaller, upper level courses within my discipline, I found my approach to learning shifted a bit. I had more opportunities for direct interaction with the faculty, opportunities to debate ideas with fellow students, and laboratory exercises that I found engaging.

For much of my undergraduate career, I never really thought of myself as a “woman in science” or about how my gender may influence how I study or view the classroom experience. That changed my senior year in college. I took an upper level Biology course that was taught exclusively in the laboratory. The faculty member was masterful. He used music and microscopes to develop a story of each microorganism. I recall being one of only a few young women in the course, and I selected the course mainly because it fit with my academic schedule. I remember the day the professor handed back our mid-term exams. He told the class about the average, which I can’t recall, and then told the class that he was “shocked” that I received the highest grade in the class. Shocked? That is a word that has echoed in my mind since that day.

What is it about me that was shocking about earning a high grade in his class? He had no previous knowledge of my work ethic or my ability. I was crushed. I continued to work hard in the course and earned an "A" but have felt like an "imposter" ever since.

The next semester helped me gain some insight into my thinking. I took a course that was cross-listed with Philosophy. The course was entitled, "Women in Science," and the professor, Dr. Margaret Palmer was and still is an inspiration to me. She opened my eyes to the personal epistemology framework and to feminist perspectives on scientific disciplines. I learned as a woman, feeling fraudulent in science has deep societal roots and is shaped by societal norms and stereotypes around gender and science. I discovered that the micro-aggression I experienced is not uncommon in the scientific disciplines.

When I moved on to a graduate program in Biology at a much smaller state university, I had the opportunity to teach a science course for the first time. I was fortunate to earn a graduate teaching assistantship which covered my tuition expenses and healthcare and provided a small stipend. I taught the laboratory section of an Anatomy and Physiology course. I loved helping students construct a well-developed understanding of the content. Being a "teacher" shifted my own approach to learning. I found myself seeking understanding and making connections while studying. I used concept maps and sought out study groups. I also had some very good teachers who incorporated small group learning, discussion, and meaning making activities into their teaching. At the time, I was taking classes, teaching 10 hours/week, and working as a research assistant in an insect neurobiology lab. My supervisor was a woman and an excellent role model for me at a young age. She included me in all grant writing activities, gave me the opportunity to partner in writing publications, and showed me how chemistry informed biology and vice versa. She helped me see how the disciplinary silos that I experienced in my undergraduate degree were not present and could not be present in the real world of scientific research. The disciplines are interwoven and connected. All these influences shaped who I became as a science learner.

Initially, I thought I would continue on to a Ph.D. in Biology. I was and still am fascinated by the content and the societal implications of good scholarly work, but my graduate program introduced me to a new love, and that is education. I moved onto a job as laboratory coordinator and instructor at a community college. I loved being in the classroom and sharing ideas with students. I wanted students to feel my passion for science and embrace the idea that to understand science content fully you need to move away from rote memorization. You need to work with the knowledge, mold it, connect it to your own earlier learning, and to the world at large. I imagine I did not do this well during my early years of teaching. I overly relied on lecture and laboratory and taught very much in the manner I had been taught during my undergraduate career. It was the fact that I had no idea how to join my desire for students to become deep conceptual thinkers with my own poor teaching skills that led me to undertake a Ph.D. program in teaching and learning. The classwork part of this Ph.D. journey went quite quickly, and I advanced to candidacy. Unfortunately, I couldn’t finish my program. I tell myself and others that this happened because I left work to stay home with my children and care for my chronically ill identical twin sister. While raising a young family and helping my sister, I think my inner voice that says, “You are still not smart enough” shaped and continues to shape my journey. I am now finally completing a Ph.D. program, but the road has been bumpy.

What I have learned throughout my graduate program has been valuable in shaping my teaching, but also my approach to student academic support. Over the years, my profession has shifted to not just teaching science, but to supporting students in their learning of science outside the classroom. I have been able to develop a successful co-curriculum to support student learning of scientific content, lead change as an administrator, and now teach students in an online environment.

My approach to teaching has changed and reflects the tenets of the reformed classroom and pedagogy of the learner-centered environment. I encourage students to think about learning and actively engage in the learning process. I assign case studies and small group discussion to allow students to make connections between the real world and move them beyond rote memorization of content. This dissertation grows out of training in biology and education, and my teaching and learner support in the biological sciences. I acknowledge that as a woman, with my own experiences of micro-aggression, imposter syndrome, and low math self-efficacy, I bring this lens to my current study. I think that it is critical for students to understand the broader context for their learning, actively engage with content during the learning process, and think about what is meaningful for their learning. As a teacher, I think we need to attend to these ideas during the curriculum development process and consider strategies that improve the learning process in the classroom for all students.

Delimitations of Study

Because this study drew from a convenience sample of three semesters of an organismal biological sciences course for biological sciences majors at a large, research-focused university, results may be generalizable only to (a) face-to-face classroom instruction where gender of instructor and classmates is more apparent; b) large research universities; and (c) undergraduate biology courses for biological sciences majors.

Limitations of Study

The following limitations are related to this study:

1- This study addressed the relationship between student epistemology and gender in a reformed learner-centered undergraduate organismal biology course at a large research university. This might limit the generalizability of the findings to organismal biology at similar institutions and may not inform courses taught at smaller institutions, in other biological science courses or pedagogical contexts.

2- I evaluated student epistemologies and epistemological change by secondary data drawn from a study that utilized the MBEX I instrument (Hall, 2013), but other tools are available that measure student epistemologies.

3- I compiled the results of honors and non-honors sections into one data set for analysis. This may have influenced some of the quantitative analysis outcomes.

4- I did not collect the data for this study myself and relied on the good data management and collection practices of the original research team.

Definition of Terms

Active Learning: A variety of pedagogical strategies that seek to engage the student in meaningful knowledge construction.

Case: "Stories with an educational message" (Herreid, 2007, p. xiv).

Case-based Instruction: An instructional approach that utilizes a subject-relevant narrative to provide a real-world context for student learning and encourages student conceptual understanding, critical thinking, scientific reasoning, and/or active learning.

Classroom Expectations: "A predictive set of ideas or assumptions students make regarding the nature of the classroom experience" (Hall, 2013, p. 1).

Cooperative Learning: An active learning strategy that involves students in working in cooperative teams to accomplish a team objective or solve a problem.

Epistemologies: "Students' views about the nature of knowledge and knowing" (Watkins & Elby, 2013, p. 274)

Guided Active Exercises (GAEs): small-group active-engagement exercises designed to engage students in active learning and knowledge construction.

MBEX I: An inventory designed to gauge student epistemologies for learning in biological sciences courses.

Traditional Instruction: A face to face teacher-centered type of instruction that involves lecturing and problem-solving rubrics.

Problem-based Learning: A type of problem-centered instructional strategy that encourages self-directed learning.

Organization of Dissertation

The first chapter of this dissertation provided a context for the need to explore the dimensions of gender and student epistemology in learner-centered undergraduate biological sciences courses. This chapter introduced the need for reform in undergraduate biological sciences education and explored the recommendations for shifts in content and pedagogy to include physical science theories and learner-centered approaches that may enhance epistemological development and increase gender equity within the STEM disciplines. Chapter Two provides a review of literature relevant to the development of the research questions. This chapter addresses the expansive literature base on women in science, the current state of undergraduate biology teaching, and epistemologies for learning science, as well as the literature related to learner-centered approaches to science instruction. Chapter Three outlines the rationale for the research design, discusses specific details of the research methods, and describes the potential limitations of the study. Chapter Four reports the results of the analyses, and Chapter Five summarizes the outcomes in the context of the literature and makes recommendations for future work.

Chapter 2: Literature Review

Science and scientific disciplines are transforming (NRC, 2009). With the emergence of new fields, such as computational biology and bioinformatics, the once disparate scientific disciplines are becoming increasingly connected. As science, scientific knowledge, and technology become more sophisticated, so do the applications of that knowledge. The NRC (2009) suggested that the biologist of the future will need to have strong quantitative, critical thinking, and analytical skills. This biologist will work on diverse, interdisciplinary teams to solve complex global problems and create technologies that will cure disease and enhance human health and longevity. These teams will be comprised of scientists who draw on their personal epistemologies and individual disciplinary perspectives and work collaboratively to create solutions. STEM graduates of the future will need to be sophisticated in their epistemologies for science learning and understand the intersection between disciplinary principles. To remain competitive in the future global marketplace, higher education will need to produce increased numbers of STEM graduates with the skills and characteristics needed to satisfy this future demand. Unfortunately, decades of research indicated that higher education institutions are missing the mark in accomplishing this goal (AAAS, 2011, 2015; Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2011; NRC, 2009).

While a robust number of students initially choose to major in a STEM field during their undergraduate program, close to fifty percent of these students will leave the STEM disciplines before graduation (NCES, 2017). Of those students who graduate with a STEM degree, women are less likely than men to pursue a profession in a STEM field, suggesting that the metaphor of a "leaky pipeline" of women in the sciences is still active in the STEM disciplines (Reuben, Sapienza, & Zingales, 2014). The complex problems of the future would benefit from an application of a diversity of perspectives. Dasgupta and Stout (2014) agreed and described this exodus of women from STEM as "untapped human capital" (p. 21). This is not stated to suggest the superiority of one gender's epistemology over another. Instead I suggest that a diversity of perspectives obtained by increasing the number of women in the STEM workforce can contribute significantly to the scientific innovations of the future (Dasgupta & Stout, 2014; Wilson & Kittleson, 2013). Such a feat can only be accomplished if a deeper understanding of how women experience science pedagogy and classrooms continues to be explored.

Women in science face a "chilly climate" where competition is emphasized, and gender stereotypes persist (Hill et al., 2010). Women in the STEM classroom often struggle with low academic self-efficacy (Hill et al., 2010; Schubert & Bowker, 2017), face implicit bias (Lindemann et al., 2016), and feel as if they are "imposters" in the science classroom (Schubert & Bowker, 2017; Yentsch & Sindermann, 2003). Critics argue that the lack of positive female role models (Young, Rudman, Buettner, & McLean, 2013), and traditional lecture-based pedagogy that emphasizes competition and isolation (Reimer et al., 2016; Hewitt & Seymour, 1991) contribute to a woman's decision to leave a STEM discipline.

While the gender gap in STEM disciplines is wider in the quantitative disciplines (e.g. engineering and physics) than in the biological sciences, many of the women who graduate with an undergraduate biology degree end up in a health-related professional field, rather than in the STEM workforce (Diekman, Brown, Johnston, & Clark, 2010; Hill et al., 2010). This may result from a better alignment of gender role stereotypes with health profession stereotypes. Women tend to gravitate to roles where they can be part of a community and be "helpful" to those within that community (Lindemann et al., 2016).

Dasgupta and Stout (2014) suggested, "Masculine gender roles align with popular cultural representations of math and science, which are portrayed as unrelated to real-world concerns and not people-oriented," (p. 22) potentially turning women away from careers in science. Women are exposed to these negative gender stereotypes in early childhood, and exposure persists throughout their academic life (Gilbert, O'Brien, Garcia, & Marx, 2014). As children develop, gender stereotypes interact with socio-cultural and institutional factors to support further the idea that STEM careers are for men.

Gilbert et al. (2014) asserted, "Negative stereotypes about the academic abilities of one's group can reduce an individual's sense of academic fit, lowering their sense of belonging, domain identification, enjoyment, and feelings of self-efficacy in their academic environment" (p. 25). Research has demonstrated that women have lower academic self-efficacy for STEM than men (Cadinu, Maass, Frigerio, Impagliazzo, & Latinotti, 2003), which leads to decreased interest in pursuing careers in STEM fields (Thoman, Arizaga, Smith, Story, & Soncuya, 2013). It may be reasoned that as biology becomes more interdisciplinary and quantitative, the number of women choosing to major in the biological sciences may decline. This suggests a continued need to gain insights into how to make the biology curriculum more relevant and inclusive for all.

While teachers and curriculum reformers should certainly attend to the barriers producing gender gaps in the STEM disciplines, there is a growing concern that both men and women educated in the biological sciences graduate ill-prepared to make adequate assessments about the scientific and ethical consequences of advancing biotechnologies (AAAS, 2011, 2015). Because biology is a foundational subject with increasing influence on individuals, society, and public policy (Bowling et al., 2008; Lanie et al., 2004), students need to develop a strong understanding of biological concepts and their relationship to foundational principles in other disciplines. Research indicates that students are unable to relate biological concepts to real-world applications and interpret the consequences of these applications (Bowling et al., 2008; Gerow, 1999; Lewis & Wood-Robinson, 2000; Wandersee, Mintzes, & Novak, 1994).

Critics of undergraduate science instruction have long blamed the popular teacher-centered lecture approach for producing students focused on memorization rather than understanding (Allen & Duch, 1998; Allen, Duch, & Groh, 1996a, 1996b; Bybee, 1997; Glasgow, 1997; Knippels, Waarlo, & Boersma, 2005; Shamos, 1995; Strenta, Elliot, Adair, Matier, & Scott, 1994; Tobias, 1990; Wheatley, 1991), and contributing to the “leaky pipeline” of women in the sciences (Hussenius, 2014; Reimer et al., 2016; Rosser, 1995). Recent research has demonstrated that the teacher-centered lecture approach also leads to negative shifts in student epistemologies for learning in biology courses (Hall, 2013). An unpublished study by Hayes-Klosteridis

(2019) confirmed that epistemologies of both men and women significantly degraded after one semester of instruction in a reformed-content, traditional-pedagogy organismal biology course (Appendix A). The shift in epistemologies from a view that is more like an expert in the field to a naïve view of biology learning might explain some of the outcomes of science instruction explored in earlier studies. To improve the outcomes of science instruction, prepare students for a future global marketplace, and attend to gender equity in the discipline, biology instruction reformers would do well to pay attention to how gender and student beliefs about knowledge and knowing manifest in the science classroom.

This chapter reviews the literature related to epistemologies for learning science and explores the current state of undergraduate biology instruction, its role in a continued gender gap in the sciences, along with suggestions for improving that instruction. Specifically, this chapter focuses on the research literature for learner-centered, active learning pedagogy that incorporates problem-centered and cooperative learning strategies.

Epistemology of Science Learning

Research into student epistemology and its relationship to science learning has a long historical tradition. This tradition has produced an array of epistemological frameworks. As outlined in Chapter One, Kelly et al. (2012) made sense of the diversity of these frameworks in the literature, by presenting three epistemological perspectives for learning in the sciences: (1) disciplinary perspective; (2) personal ways of knowing perspective; and (3) social practices perspective. This section highlights a few representative examples from each framework, examines how the three perspectives overlap, and suggests a model that can be used as a lens for viewing the relationship between epistemologies and gender in learner-centered, undergraduate biological sciences courses.

Disciplinary Perspective Framework

According to Kelly, Chen, and Crawford (1998), "Becoming a scientist involves coming to see the world in a particular way; coming to understand, use, and draw upon a common body of knowledge; coming to understand how to articulate an appropriate argument given certain contexts; and coming to know how to present oneself and one's data in socially and scientifically appropriate ways" (p. 24). Researchers evaluating learning in the sciences from this perspective are concerned with the ways in which students develop skills and knowledge consistent with how scientists practice their discipline as a distinct way of understanding the nature of knowledge. According to Bowling and Martin (1985), "Science acts like a lens through which the world is perceived and as a filter through which potential knowledge is channeled" (p. 309). The goal for science instructors is to produce students with a more sophisticated view of the nature of scientific knowledge; in essence, a view that is more like a scientist. Since learning scientific principles takes place within the construct of the scientific discipline, it is important to consider the manner in which disciplinary knowledge and expectations intersect with student learning in the science classroom.

Lederman and Lederman (2004) outlined beliefs about the nature of scientific knowledge (NOS) that they consider important to framing science instruction. The first view is that scientific knowledge is a construct that results from the interplay between observation and inference. In this empirical model, the inference must be verifiable. For example, a biology student may observe an insect with eight legs and make an inference that the insect must be a spider. Scientific laws build on observations and describe observable fact. Theories on the other hand “are inferred explanations for observable phenomena” (p. 37). These dimensions are central to the scientific process and to theory building. Scientific laws and theories must be verifiable and “checked against what actually occurs in the natural world” (Lederman & Lederman, 2004, p. 37). In the example, the student would have to verify the inference that the insect is a spider by comparing the insect to spiders and other insects for confirmation.

While development of scientific knowledge follows an empirical method, it can also be creative and subjective. In this sense, science knowledge is subject to interpretation. Scientists are human beings who bring to the science world inherent personal views of knowledge, prior experiences and biases, which can affect their work. This subjectivity is not only individually constructed but is developed within a sociocultural context. The scientist must make meaning of new information in the context of their personal experience and time that the data were collected. In this way, scientific knowledge is not concrete; instead, it is tentative and subject to change as new information emerges. Observation and inference are only accurate with respect to the information scientists have at the time the observation is made. For example, when Jean-Baptiste Lamarck proposed the idea that traits acquired during an organism’s lifetime are heritable, he was working within a paradigm that shaped science thinking for the previous two thousand years. He proposed that body parts that were used repeatedly grew bigger and stronger, while underused body parts became obsolete. These traits, he believed, could be passed on to offspring. To support his work, he examined fossils and compared them to animals in nature. This is the essence of the scientific method. Lamarck observed something in nature and made an inference that with the available knowledge at the time was verifiable. When Darwin proposed his theory of evolution, he rejected the work of Lamarck and created a new paradigm for inheritance patterns based on his observations and inferences. In this sense, science knowledge is not concrete and is subject to reinterpretation as new evidence emerges.

Scientific knowledge development can be viewed as residing on a continuum from naïve to expert. Students who believe that scientific knowledge is produced when unrelated facts, disconnected to the real-world, are regurgitated from an authority figure to the student are considered on the naïve end of this continuum. While students who actively construct knowledge, make connections within and between disciplinary content, and seek to understand principles are viewed as being more sophisticated. Studies suggest that students with naïve perspectives (e.g. science is concrete) struggle with content retention (Lising & Elby, 2005) and conceptual understanding (Hammer, 1994). To improve these outcomes, researchers working within the disciplinary perspectives framework explore ways to improve conceptual understanding through pedagogical practices that advance conceptual change (Duit & Treagust, 2003; Duit, Treagust, & Widodo, 2008).

The central tenet of conceptual change research is that misconceptions can be acknowledged by the learner, faculty can design instruction to support conceptual change, and misconceptions can be replaced by more sophisticated interpretations. Arner-Welsh (2010) suggested, "Conceptual change research focuses on the process by which students come to understand content – possibly by replacing naïve or simple concepts with more scientific or complex ones" (p. 19). While it is essential to acknowledge that scientific knowledge is bound within the context of a discipline and follows the norms and empirical rules associated with theory development, science learning is more than shedding a misconception and replacing it with a more mature stance. As we see in the example of Lamarck, he constructed an understanding of the natural world based upon his observations of it. His inferences and ultimate theory development were bound within the social context of his time. The idea that knowledge is constructed by the learner, and has a social context, is also central to the other two perspectives overviewed in this chapter (Figure 1).

Within the frame of the disciplinary perspective certain critics have argued that the epistemology of the scientific disciplines is inherently masculine in nature (Fox Keller, 1985). Fox Keller suggested that the historical construction of scientific disciplinary knowledge is represented in ways that are symbolically male. Fox Keller's beliefs are echoed by Sandra Harding (1992) who suggested that the historical construction of science as a discipline is inherently patriarchal (establish men as the central authority) and the values of science culture are masculine (objectivity, order, competition), not feminine (intuition, collaboration). There is a hierarchy in the scientific domain that creates a male/female duality (Brickhouse,

2001) that favors men and places women in opposition. These feminists rejected the objectivity and norms of science in favor of a new model of epistemic values.

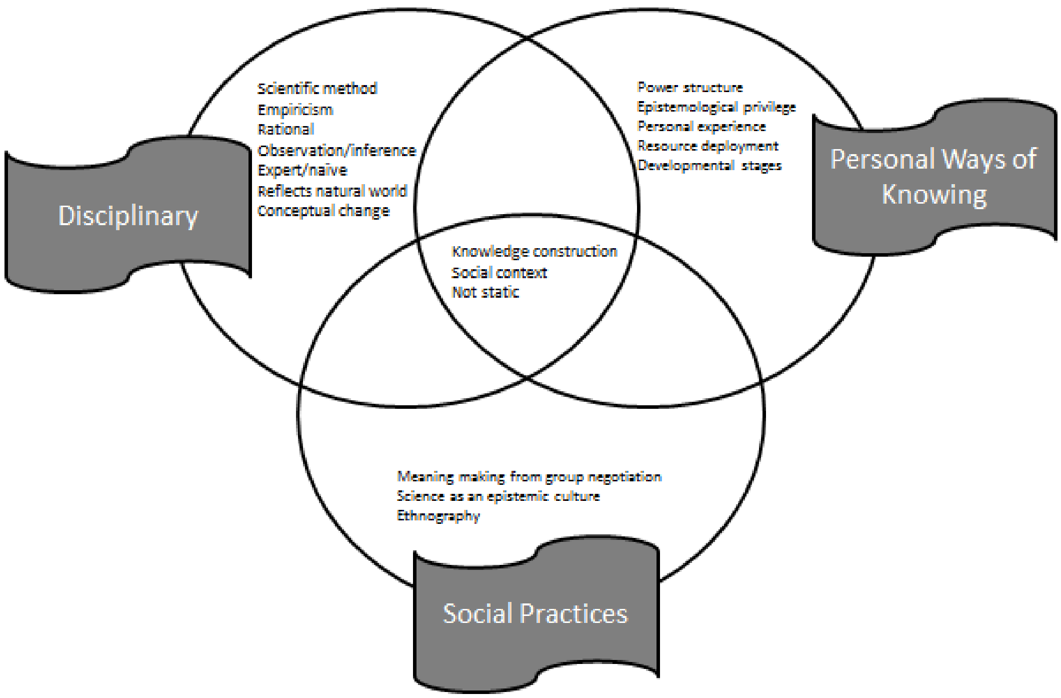

Figure 1. Relationship between the Disciplinary, Personal Ways of Knowing, and Social Practices Perspectives

Kelly et al. (2012) suggested that knowledge construction occurs within a social context of a learner's community and cannot be free of the values these communities hold. From this viewpoint, it follows that when scientific knowledge is presented in a lecture course as being purely objective, women may experience a clash between their personal way of knowing and the epistemic norms of the scientific disciplinary perspective.

Other feminists accept the traditions of objectivity and theoretical validations that exist within their scientific discipline (Belenky, Clinchy, Goldberger, & Tarule, 1986), and seek to promote opportunities for knowledge construction within this environment. Brickhouse (2001) argued, “In order to understand learning in science, we need to know much more than whether students have acquired particular scientific understandings. We need to know how students engage in science and how this is related to who they are and who they want to be” (p. 286). While a discussion and critique of the diversity of feminist viewpoints related to scientific knowledge is beyond the scope of this study, I acknowledge that I accept the possibility that disciplinary knowledge and ways of knowing in science have been constructed in a way that may be unique to the sciences. I also believe that women may bring a different lens, or personal way of knowing to the construction of scientific knowledge and participation in scientific discourse.

Personal Ways of Knowing Perspective

Champions of the personal ways of knowing perspective for viewing science learning are “concerned with the ways individual learners conceptualize knowledge and how such personal views of knowledge influence their learning” (Kelly et al., 2012, p. 282). Within this framework there are “three distinct perspectives on personal epistemologies: the study of epistemological development, epistemological beliefs, and epistemological resources” (Arner-Welsh, 2010, p. 11).

The developmental perspective of the personal ways of knowing framework evolved from the work of Perry (1970). In his seminal work, Perry interviewed 140 male student volunteers at Harvard University to explore their perspectives on knowledge and knowledge development. He conducted this study over four years to explore how their perspectives changed during the course of their academic progression. His analysis suggested that students develop knowledge in stages. In the earliest stage, the dualistic stage, students view knowledge as something transmitted by an authority. In this sense, knowledge is something that is absolute and transferrable. As a student becomes more sophisticated in his/her reasoning, he/she will become more reflective and develop an understanding of how knowledge is constructed.

Building upon Perry's developmental framework, Belenky et al. (1986) described the role gender plays in knowledge development by presenting five "ways of knowing" — silence, received knowledge, subjective knowledge, procedural knowledge, and constructed knowledge. Silence and received knowledge are similar to Perry's early dualism stage, where students view knowledge as concrete and transmitted to the student by an authority. Silence in the "Women Ways of Knowing" (WWK) framework adds the view that at this early stage women are voiceless. In the subjective stage, women begin to gain a voice, but still are more dualistic in believing in absolutes (right/wrong/good/bad). Procedural knowledge is either connected or separate knowledge.

According to Khine and Hayes (2010), "Connected knowers do not seek logical or empirical explanations for a position; their aim is to understand the position rather than to test its validity" (p. 186). Their thinking is intertwined with feelings and emotion. This is different than the disciplinary perspective that seeks to validate inferences. Separate knowers are more detached and critical. They may argue and debate an idea or concept. Constructed knowledge is similar to Perry's commitment to the relativism stage, where students view knowledge as constructed by an individual. The developmental frame is "broad and general" (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008, p. 282) with the underlying understanding that views of knowledge are uniform and can be applied consistently across domains.

Theorists working from the personal epistemological beliefs framework define beliefs about knowledge and knowing more narrowly. This perspective "can best be understood as a collection of beliefs about knowledge and learning, and that these beliefs might be more or less independent, rather than existing in integrated fashion and developing in a coordinated sequence" (Hofer, 2004, p. 45). This framework grew out of the early work of Schommer (1990), who described a multidimensional model of epistemological beliefs. In her model, epistemological beliefs included the "structure of knowledge (ranging from simple to complex), the stability of knowledge (certain to uncertain), the source of knowledge (omniscient authority to reason and evidence), the speed of learning (quick to gradual) and the ability to learn (fixed to improvable)" (Schommer-Aikins & Duell, 2013, p. 318). The beliefs in this sense are individual, relatively stable, context-independent, and accessible by the individual. Using a variety of epistemological questionnaires, researchers in this vein concluded there is a relationship between epistemological beliefs and academic performance (Schommer-Aikins & Easter, 2006), motivation (Muis, 2004), gender (Hofer, 2000; King & Magun-Jackson, 2008), student learning (Hofer, 2000), and engagement (Kardash & Howell, 2000).

King and Magun-Jackson (2008) conducted a study of 396 university undergraduate and graduate engineering majors to examine the relationship between educational level and epistemological beliefs. The researchers used the Schommer Epistemological Questionnaire (SEQ), and discovered that background characteristics (gender, level in school, race) were predictive of student epistemological beliefs. The SEQ is a Likert-scale instrument that evaluates student epistemological beliefs along four dimensions: structure of knowledge, certainty of knowledge, control of knowledge, and speed of knowledge (King & Magun-Jackson, 2008). Similar to other models, the dimensions include a continuum of naïve to sophisticated techniques. The researchers evaluated 370 returned surveys (304 male/ 62 female) and conducted one-way ANOVA to explore the relationship between background variables. With respect to gender, the authors concluded that female undergraduate engineering students were "less likely than the males to have beliefs in fixed ability and quick learning" (p. 61). The authors suggest that the original Schommer (1990) questionnaire has been widely criticized and may have not produced valid results. I would also suggest that while the overall *n* of the study was robust, the number of men (304) in the study is substantially larger than the number of women (62), potentially influencing the outcome of the analyses. Schraw (2013) furthered this assessment and argued that outcomes are largely sample-dependent when using these types of factorial models to examine student epistemic beliefs. These results are mirrored by the work of Paulsen and Wells (1998), who also found that women were more sophisticated than men in their beliefs related to those categories. Hofer (2000) found that men were more likely than women to hold naïve epistemic beliefs related to the source of knowledge. Men in her study viewed authority as the source of knowledge, while women were more mature in their beliefs.

Other studies provided conflicting evidence, where women hold less sophisticated epistemological beliefs than men. In a quantitative study of 520 undergraduate Taiwanese biology students, researchers concluded that there were significant gender differences in epistemic beliefs about the source of knowledge and approaches to learning in the discipline (Lin, Liang, & Tsai, 2012). The researchers in this study used the Epistemic Beliefs in Biology (EBB) survey (Conley, Pintrich, Vekiri, & Harrison, 2004) to explore the relationship between gender and student epistemic beliefs, and a modified Approaches to Learning in Biology (ALB) questionnaire (Lee, Johanson, & Tsai, 2008) to explore student approaches to learning in biology. Their adaptation of the EBB survey measured "beliefs in terms of four factors: source, certainty, development, and justification" (p. 799). The category of source assesses where the student located the source of knowledge. A naïve student viewed the source of knowledge as deriving from a single authority figure, while a sophisticated student acknowledged multiple sources of knowledge. Students who viewed biological knowledge as certain suggested a dualistic right/wrong answer. According to the model, students who considered that biological knowledge has the potential for change were more mature in their epistemological stance.

Lin et al.'s (2012) results suggested that women were more likely than men "to believe in authority and the certainty of knowledge" (p.799), thereby signifying a less mature epistemological stance. These results indicated that women approached biology learning from a more surface approach and males were more likely to fear failure in the course. According to women theorists in science, such a result would make sense provided that the large lecture creates a classroom culture where scientific knowledge is passively received from an authority figure and men are motivated by competition and goal accomplishment. The researchers recommended that biology educators "provide more assistance to female students in order to be aware of their beliefs, to understand how their beliefs might influence their approaches to learning, and to recognize the related jobs in the field inherited humanistic and helping values" (p. 804). While these authors provided good evidence that female university biology majors have less mature epistemic beliefs and less sophisticated approaches to learning subject material, they advised the reader to consider the role pedagogical context may play in producing these phenomena. Using a large-scale, multi-stage cluster sample of university students, Manavipour (2013) found women to be less sophisticated than men in certainty of knowledge on Schommer's questionnaire. There were no significant gender differences across other categories of the model.

While there is some evidence to support a relationship between gender and epistemic beliefs, the results have largely been inconsistent (DeBacker et al., 2008) and dominated by quantitative analyses. Perhaps the relationship between gender and epistemic beliefs in science cannot be understood with a quantitative analysis alone. By utilizing a mixed methods design, qualitative analysis may be able to expand the quantitative outcomes evidenced in the studies discussed previously and complement our understanding of the complexity of the phenomena.

Hammer and Elby (2003) contended that personal epistemologies are not independent of context and suggested a finer grain of analysis, or a resource framework for understanding epistemic beliefs. Researchers who take the epistemological resources approach “examine the resources and tools learners apply in specific situations” (Arner-Welsh, 2010, p. 14). In this frame, knowledge construction is not about identifying an inaccurate conception and replacing it with a correct one or more like an expert’s view of science; rather, it is about how students reason using the cognitive resources they have available to them (Hammer et al., 2005). When a student repeatedly activates a set of resources, the resource can “become a cognitive unit itself” (Hammer et al., 2005, p. 99). The purpose of the instructor in this sense is to guide students in identifying their thoughts about knowledge and learning. Students with a more sophisticated view of scientific knowledge can apply resources accurately during reasoning in a particular context and “would produce a different pattern of activation/application of knowledge in future responses” (Dufresne et al., 2005, p 190). Application of these resources can happen within the context of another course within the discipline, outside the discipline, or outside the academic context.

By way of example, Hammer et al. (2005) shared the story of a young, male physics student, Louis, who was more naïve in his views of the nature of knowledge when he was studying for his physics class, but much more sophisticated in his view when he was tutoring other students. The authors maintained that in his role as tutor, “Louis activated *knowledge as constructed*, a resource for understanding knowledge as built from other knowledge” (p. 93). Arner-Welsh (2010) suggested that learning in the science disciplines for women reflects “their management of both the personal epistemologies they bring with them into the classroom (in the form of patterns of use of epistemological resources and deployment of epistemological discourses) and the scientific disciplinary epistemology which underlies much of the content they are learning in science class" (p. 34). In the science classroom where cooperative learning is purposefully incorporated into the learning dynamic, combining the social practices perspective with the personal ways of knowing perspective can aid our understanding of student learning in a scientific discipline (Figure 1).

Social Practices Perspective

The social practices perspective considers "how through particular learning events, questions of justification, reasonableness, and knowledge claims are negotiated among members of a group. This view describes the ways that being a member of an epistemic culture, observing from a particular point of view, representing data, persuading peers, engaging in special discourse, and so forth, locally define knowledge" (Kelly et al., 2012, p. 282). Students enter the modern biology classroom with beliefs about science and learning in the sciences that link to the sociocultural context in which they developed. Research in this vein is typically ethnographic in nature and seeks to explore how students develop meaning within a social context. In essence, researchers explore not only questions about science knowledge construction but are concerned with the manner in which this knowledge is constructed in relation to the negotiation of meaning within a group.

Kelly, Chen, and Prothero (2000) conducted an ethnographic study of oceanography students to explore how knowledge in this course was constructed through interaction. They suggested that "by viewing science as culture and practice (e.g., conventionalized ways of knowing, speaking, acting, being), the activities associated with knowledge-in-use of practitioners become relevant for initiating newcomers into a community" (p. 694). When viewed as an epistemic culture, a scientific discipline establishes norms for how knowledge is constructed. The social practices perspective expanded the disciplinary and personal ways of knowing perspectives by acknowledging that human beings are inherently social primates who developed in a particular social context and bring this lens to the interpretation of natural phenomena.

Much of the work in the domain of personal epistemologies combines frameworks for a richer view of student learning in the sciences. Employing Wenger's view of science knowledge development taking place in a community of practice, Rizk, Jaber, Halwany, and BouJaoude (2011) explored the relationship between student background characteristics (major, gender, religion) and student epistemologies of 213 undergraduate sophomore science majors. They conceptualized gender "as determinant of a way of being, a way of living, hence a community of practice" (p. 478). The researchers combined semi-structured interviews with thirty students and results from student answers on Hofer's Science Focused Epistemological Beliefs Questionnaire (Hofer, 2000). The interview instrument was adapted from the Views of Science-Technology Questionnaire (Dogan & Abd-El-Khalick, 2008). Researchers selected 30 students for the interviews based on their level of sophistication along a naïve/informed continuum. Using factor analysis, the researchers determined there was no significant relationship between gender and epistemological beliefs, but biology majors had more sophisticated beliefs on the epistemological dimensions measured by the instrument. Given the mixed results from other studies exploring gender and epistemologies, the result was not surprising to the authors. Qualitative analysis of the semi-structured interviews did not align well with the outcomes of the quantitative portion of the study, and the researchers were unable to identify any gender-specific themes in student responses. The researchers coded the interviews in each of the four dimensions that aligned with the quantitative instrument, thus confining the coding process into those categories. While Rizk et al. (2011) found qualitative analysis important to their exploratory study, they felt limited in their "ability to responsively attend to the emergent and contextual nature of beliefs" (p. 493). Despite this challenge, they concluded that "in order to assess students' epistemologies, one must consider a variety of research approaches that can together contribute toward painting a more holistic picture of students' epistemological beliefs" (p. 494).

Arner-Welsh (2010) also explored the relationship between gender and epistemologies from a combined theoretical lens. She asserted that women are raised within a particular social context that shapes how they view science and scientific knowledge. As girls develop into women,

> not only are they steeped in a variety of discourses about what it means to be female (including how girls and women should approach knowledge) but most importantly they are developing in a world which provides them with particular (gendered) experiences, which help to shape the kind of person - and thinker - they become. As active agents, girls may deploy, resist and transform these discourses, and make a variety of meanings from their

> experiences; nonetheless, these gendered discourses and experiences provide a large part of the context and resources available to them as developing thinkers. (p. 2)

While Arner-Welsh conducted her research with ninth grade science students, her description of how the social construction of gender and scientific disciplinary epistemology interact provided a framework that I found helpful in understanding the nuanced relationships between the three epistemological perspectives. How women and men view knowledge and knowledge construction in science is a complex topic with underlying social, disciplinary, and personal epistemology dimensions. In conceptualizing this study, it was not my intent to minimize and/or overstate the complexity of this relationship. Rather, my goal was to build on the good work of the researchers who preceded me.

The studies presented in this section of the literature review present conflicting views of the relationship between gender and epistemology in the scientific disciplines and across epistemological perspectives. Much of the research conducted to date has been exclusively quantitative or qualitative in a nature. While such a singular approach has added value to our understanding of the complex relationship between gender and epistemology, mixed methods approaches may provide us with a more nuanced view. The current study addressed this gap, by integrating the analysis of semi-structured interviews with quantitative MBEX I (Appendix B) survey data to explore the dimensions of gender and epistemologies in a learner-centered classroom. The study drew on the intersection between the disciplinary, ways of knowing, and social practices perspectives (Figure 1) to inform the exploration of the relationship between gender and epistemology. While, many of the researchers in this tradition have focused on elucidating the potential relationship between gender and epistemology and recommend that teachers design courses, curriculum, and student support to improve the sophistication of student epistemologies, few studies made concrete recommendations on how such changes could be manifested in the classroom. The next section of this chapter explores the current state of undergraduate biological sciences instruction and potential of learner-centered instruction to improving student learning in biological science courses.

State of Undergraduate Biological Sciences Instruction

Biology is a conceptually rich academic field with infinite applications in the real world (Knippels et al., 2005). Today, advances in the life sciences are transforming our understanding of basic genetic mechanisms of disease, improving agriculture, and increasing human longevity. Biological advances have fundamentally changed the world in which we live. Advances in DNA sequencing technology will change medical approaches to personal genomics and clinical diagnostics. The discovery of the BRCA1 gene and subsequent development of a clinical test for its presence, allowed “high-risk” women to choose prophylactic mastectomy, rather than waiting for a breast cancer diagnosis. Advanced warning systems of this kind are decreasing mortality and slowing the progression of disease. In order for biologists of the future to make well-reasoned decisions, they will need to think critically about biological concepts and connect them to other disciplinary principles their real-world applications.

Today, most biology majors learn basic concepts in introductory courses taught in large lecture classrooms. This approach to teaching undergraduate biology is widely criticized for missing the mark at producing students who can think critically about biological concepts (Bowling et al., 2008; Dikmenli, Cardak, & Kiray, 2011; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000). These same critics argued that the teacher-centered approach produces students with an incomplete understanding of concepts and an inability to apply these concepts to ethical and scientific problems related to applications of biology in the real world. Critics also maintained that the traditional teacher-centered approach to instruction favors competition rather than collaboration, negatively impacts student epistemologies (Hall, 2013; Lising & Elby, 2005), and influences women's decisions to persist in the sciences (Hewitt & Seymour, 1991).

Teacher-centered Instruction

The teacher-centered approach to instruction has deep roots in higher education. In this model, the teacher is the expert, and the student is the passive recipient of the teacher's knowledge. The teacher directs the learning process for the student by controlling the delivery of the content, and then tests the student on how well he/she learned that content. This long utilized and still popular approach in higher education emerged theoretically from behaviorism, whose theorists maintained that behavior is shaped by stimuli and response. When translating this philosophy to teaching and learning, the underlying assumption is that knowledge held by a teacher can be transmitted to a student as a stimulus to the learning process (Jonassen &

Land, 2012). Learning in this philosophy is a behavioral change that occurs in response to a stimulus. Hancock, Bray, and Nason (2002) defined teacher-centered instruction as follows:

> The teacher (a) is the dominant leader who establishes and enforces rules in the classroom; (b) structures learning tasks and establishes the time and method for task completion; (c) states, explains, and models the lesson objectives and actively maintains student on-task involvement; (d) responds to students through direct, right/wrong feedback, uses prompts and cues, and, if necessary, provides correct answers; (e) asks primarily direct, recall-recognition questions and few inferential questions; (f) summarizes frequently during and at the conclusion of a lesson; and (g) signals transitions between lesson points and topic areas. (p. 366)

The most popular types of teacher-centered approaches are demonstration, lecture, and lecture-discussion. During demonstrations, the teacher uses models, equipment, tools, and/or supplies to demonstrate a skill or a concept. In the science classroom, an instructor may demonstrate how to remove the exterior skin of an animal during dissection or the appropriate laboratory technique for pipetting a solution. In a lecture, teachers often transmit large amounts of content to students, who sit quietly, taking notes and absorbing the information. During lecture-discussion, faculty may lead a discussion to explore a topic related to the lecture and drill students with questions. All these approaches put the student in a passive role in the learning process (Knight & Wood, 2005).

Critics blamed the teacher-centered approach to undergraduate biology instruction for students' fragmented, compartmentalized, and inaccurate understanding of basic biology concepts (Dougherty, 2009; Marbach-Ad, 2001; Smith & Knight, 2012). They contended that faculty in large lecture courses rely heavily on textbooks, inadequately sequence subject matter (Knippels et al., 2005), compartmentalize topics (Murray-Nseula, 2011), and emphasize rote memorization of content (Blumenfeld, Kempler, & Krajcik, 2006). According to Murray-Nseula (2011), most genetics courses within the biological sciences undergraduate curriculum "end up being an encyclopedia of genetics information, understanding of which is often complicated by the discipline-specific vocabulary and terminology" (p. 75). Murray-Nseula (2011) and Marbach-Ad and Stavy (2000) concluded that the teacher-centered approach to instruction in biological sciences courses fails to teach students the type of multi-level thinking needed to comprehend complex mechanisms. Later on, these students may not be able to make well-reasoned decisions about scientific information and its application. This "sage on the stage" approach reinforces the naïve epistemologies students bring to the biological sciences classroom (Hall, 2013), perpetuate "stereotype threat" and "imposter syndrome" (Lindemann et al., 2016), and promote low STEM self-efficacy (Hill et al., 2010).

Newman et al. (2012) conducted a robust study of undergraduate biology students enrolled in large lecture cell biology and molecular biology courses. They found that advanced students were challenged when they attempted to apply an understanding of chromosome structure to problems of meiotic cell division. These students had multiple exposures to this content in pre-requisite lecture courses, yet could not think critically about the topic. The authors also concluded that students could not integrate knowledge about heredity and chromosomal structure when taught with the traditional teacher-centered approach.

A qualitative analysis of 140 science student teachers noted that the majority of study participants had scientifically valid conceptions about the gene concept, but their understanding did not “correspond to the scientific gene description of modern genetics” (Dikmenli et al., 2011, p. 2612). Over 55% of the student teachers responded that the gene is the basic unit of heredity but failed to understand the cellular basics of chromosome formation. For example, several study participants suggested, “Chromosomes are formed with the uniting of genes” (Dikmenli et al., 2011, p. 2611). In actuality, chromosomes consist of long strands of DNA of unknown function interspersed with genes. Student teachers also held misconceptions about the function of the gene, its relationship to DNA translation, and the ultimate expression of protein. For instance, two student teachers said that a “gene is the smallest coded protein within the body” (Dikmenli et al., 2011, p. 2611). The gene is the basic unit of inheritance in that it includes DNA that is transcribed into RNA and then translated into protein.

Smith and Knight (2012) said that misconception is a term “generally reserved for times when students exhibit stable and coherent false beliefs” (p. 28) and suggested that certain misconceptions are resistant to change. They argued that learning can only occur when students “relinquish alternative conceptions in favor of scientific ones” (p. 28). Smith and Knight’s (2012) study utilized the Genetics Concept Assessment (GCA) to explore student misconceptions about genetics. Their study was conducted with 751 undergraduate genetics students in six different courses at the University of Colorado, Boulder. Using a post-test analysis of the GCA, the researchers determined that despite instruction, students at post-test continued to hold misconceptions about “genetic content and genetic code” (p. 24). These findings are consistent with earlier studies that conclude students’ understanding of basic genetic concepts is naïve and often inaccurate (Lewis & Wood-Robinson, 2000). For example, students often can memorize the definition of “gene” but fail to make the connection between the gene and the final phenotype of an organism (Lewis & Kattmann, 2004). They also do not understand the important relationship between the gene and protein expression or how to calculate probability (Lewis & Wood-Robinson, 2000; Marbach-Ad & Stavy, 2000). This framework aligns with the disciplinary perspective of science learning. In this vein, a student’s incorrect view of the gene is opposed to the contemporary scientific wisdom. Instructional innovations guided at improving these misconceptions, might fall short if we fail to acknowledge the relationship between these misconceptions and the epistemic beliefs the student holds in the science classroom.

While negatively impacting cognitive and epistemological outcomes, critics also maintain that the traditional lecture approach promotes a “weed out” culture (Hewitt & Seymour, 1991) leading to lower representation of women in the STEM disciplines. A recent multi-year, multi-method study conducted at a large institution highlighted institutional factors that impact women’s STEM participation. Lindemann et al. (2016) suggested that the large class size of the STEM classroom leads to “stereotype threat” and “imposter syndrome” which impacted women’s STEM identity. In their focus group interviews women expressed concern with perceived competition in the science classroom and felt their courses were not connected to the real world. Women in their study were drawn to STEM because they felt the discipline would help them pursue careers that would allow them to “make a difference.” When women don’t find a connection between what they are learning in the classroom and their future career, they change their major.

Another cultural norm that plays out in the large lecture classroom is the stereotype that the best scientist is male. In these environments, women often can’t align with the identity of the scientist and feel isolated (Yentsch & Sindermann, 2003). When a woman doesn’t see herself in STEM, she can develop a sense that she is an “imposter” in the science classroom. Cheryan, Ziegler, Montoya, and Jiang (2017) suggested that the masculine culture of the STEM classroom interacts with women’s level of academic self-efficacy. Given that women tend to prefer more collaborative approaches to learning, the large lecture format may influence the discrepancy between STEM self-efficacy between women and men (Schubert & Bowker, 2017). Men tend to thrive in highly competitive classroom environments and disciplines, so perhaps the lecture environment is more aligned with a male perspective.

The research on conceptual understanding, stereotype threat, imposter syndrome, and self-efficacy provides compelling examples in support of the need to improve student learning experiences and attend to the creation of a gender-neutral culture in the sciences. As the field of biology advances and becomes more intertwined with other scientific disciplines, the biologist of the future will need to work in teams to solve complex problems. New approaches to instruction could support diversification in the sciences while attending to student conceptions about the nature of scientific knowledge and knowing. Promising instructional methods for meeting these goals involve shifting the science classroom from a teacher-centered to a learner-centered environment that provides educational opportunities to meet the needs of diverse learners in the classroom.

Learner-centered Instruction

Learner-centered instructional strategies are founded on the principles of constructivist learning theory. In this cognitive model, learning needs to be active and authentic for meaningful conceptual development and understanding to occur (Cakir, 2008) and is the result of building upon prior knowledge. This theoretical approach to learning builds on the work of Jean Piaget (2013), Lev Vygotsky (1978), and David Ausubel (1963).

For Piaget, learning was a process that occurs through stages. This learning requires the active construction of knowledge by the learner. Learning in this view does not take place as a behavioral response to stimuli presented to a blank slate, but rather as a process of classification and meaning making built on earlier schema (Piaget, 2013). Piaget (2013) described four stages of cognitive development for children: sensory-motor, pre-operational, concrete operational, and formal operational. Adult learners, being at the formal operational stage in Piaget’s model, can think logically and test hypotheses to expand their knowledge base. Similarly, for Ausubel, “meaningful information is stored in networks of connected facts or concepts referred to as schemata. New information, which fits into an existing schema, is more easily understood, learned, and retained than information that does not fit into an existing schema" (as cited in Cakir, 2008, p. 194). When information is compartmentalized, or learning is rote, the knowledge often does not fit into a pre-existing schema and is more difficult to learn and retain (Ausubel, 1963). In this situation, the learner experiences a sense of dis- equilibration and must accommodate the new knowledge by developing new cognitive schema (Piaget, 2013). Since Piaget and Ausubel emphasize cognition, this constructivist approach is often referred to as cognitive constructivism.

Like his cognitive constructivist counterparts, Vygotsky (1978) theorized that learning is bounded by a student's developmental ability and his or her ability to learn new content. Where he differed from the cognitive constructivists is in his assertion that learning occurs best in a social context. Thus, his model is referred to as social constructivism. In Vygotsky's model, students can learn beyond their developmental level through social interaction with anyone who is more knowledgeable than they are on a particular topic. The "more knowledgeable other" (MKO), as Vygotsky described, can be a teacher, coach, or a peer. In Vygotsky's model, learning is a shared, collaborative process that occurs in a "zone of proximal development" (ZPD). This zone is the space between a learner's ability to complete a task with MKO supervision and completing a task independently (Driscoll, 2005).

Building on these theories, modern constructivism propagates the idea that "learning is achieved by the active construction of knowledge supported by various perspectives within meaningful contexts and social interactions" (Kundi & Nawaz, 2010, p. 31). Learning in this context is “a process of personal understanding and the development of meaning where learning is viewed as the construction of meaning rather than as the memorization of facts” (Kundi & Nawaz, 2010, p. 31). Learning is an active social process in which students develop new knowledge constructs in relation to their current knowledge. If this idea is applied to curriculum development, it creates a teaching environment juxtaposed with the teacher-centered behaviorist model (Table 1).

Table 1 Contrasting Characteristics of Behaviorist and Constructivist Pedagogy

	Behaviorism	Constructivism
Role of the Teacher	Director of learning	Facilitator of knowledge development
Role of the Student	Passive recipient	Active knowledge constructor
Course Content	Emphasis on basic skills Content is fixed	Emphasis on connections
Student Learning	Emphasis on rote memorization	Learning is active and interactive
Classroom	Teacher-centered	Learner-centered

Constructivist pedagogies acknowledge the role of the learner in the learning process and emphasize active, learner-centered processes. The modern interpretation of constructivism is also aligned with the epistemological perspectives for science learning presented earlier in this chapter. All three epistemological perspectives suggest that knowledge is ultimately constructed by the learner and involves social interaction.

The applications of constructivism to undergraduate biological sciences instruction vary widely (Mintzes, Wandersee, & Novak, 2005), but all approaches emphasize the role of individual learners in constructing their knowledge base and seek to create a learner-centered classroom. Examples of learner-centered pedagogies used in undergraduate science courses include: active engagement (FitzPatrick, Finn, & Campisi, 2011; Hall, 2013); case-based learning (Murray-Nseula, 2011); web-enhanced case-based learning in undergraduate microbiology (Smith et al., 2005), and collaborative learning (Hall, 2013). Despite the variation in techniques, learner-centered instructional models used in undergraduate science instruction have been successful in increasing retention of content knowledge and improving critical thinking skills (Knight & Wood, 2005), shifting students' epistemologies to more sophisticated stances (Hall, 2013), and decreasing the sense of competition while increasing collaboration in the classroom (Reimer et al., 2016). This type of learning environment is also purported to be more supportive of a woman's way of learning in the sciences (Belenky et al., 1986). The small-group, active-engagement exercises (GAEs) used to engage students in this study's learner-centered classroom, drew from popular learner-centered instructional models – cooperative learning and problem-centered instruction.

Cooperative learning. Across the country, institutions of higher education are incorporating cooperative learning approaches into their practices. At its core, cooperative learning involves structured collaborative group work "where students pursue common goals while being assessed individually" (Prince, 2004, p. 223). Prince (2004) distinguished cooperative learning from the broader field of collaborative learning by suggesting that "collaborative learning can refer to any instructional method in which students work together toward a common goal" (p. 223). While collaboration amongst peers is central to both definitions, interaction in the cooperative learning environment is more structured. For cooperative learning to be beneficial to the learning process, students must have a sense of accountability to their individual, as well as group, goals (Johnson & Johnson, 2009). Much of the research on cooperative learning contrasts this active group process with the traditional lecture approach.

In a meta-analysis of cooperative learning conducted by Kyndt et al. (2013), researchers found significant positive effects for cooperative learning on achievement, attitudes, and perceptions over the 51 studies examined. Authors of earlier reviews of cooperative learning approaches in STEM courses concluded that cooperative learning methods also positively impacted student persistence in the sciences (Springer, Stanne, & Donovan, 1999), promoted positive attitudes toward science learning (Johnson, Johnson, & Smith, 2007), improved engagement by women (Rodger, Murray, & Cummings., 2007), and produced favorable shifts in student epistemologies in the biological sciences (Hall, 2013). In fact, studies demonstrated that opportunities to engage in active, collaborative learning produced higher learning gains for both men and women (Normandeau, Iyengar, & Newling, 2017).

Rodger et al. (2007) explored the relationship between gender, cooperative learning, and achievement in a large university classroom. They randomly assigned 80 men and 80 women to either a cooperative learning classroom or traditional classroom. They assessed achievement using a multiple-choice test and a mini-assignment. They found no gender difference on the multiple-choice test between the two treatments but concluded that women scored significantly higher on the mini-assessment if they participated in the cooperative classroom. The authors suggested, "It is possible to perceive learning as a social activity that can be moderated by social interdependence and independence. If women have more positive attitudes than males toward cooperation and social interdependence, then it follows that learning methods that allow for the development of trusting and interdependent relationships should be effective for women" (Rodger et al., 2007, p. 160). In this study, men scored higher on the multiple-choice test than did women in both learning environments. Stanger-Hall (2012) suggested that there is inherent gender bias in multiple choice exams, so this outcome was predictable.

Problem-centered instruction. Problem-centered approaches to instruction include Case Based Instruction (CBI) and Problem-based Learning (PBL). CBI is a learner-centered model with proven success at improving conceptual understanding of scientific principles (Hoskinson, Caballero, & Knight, 2013; Murray-Nseula, 2011). According to Terry (2012):

> The case study method allows students to use their prior knowledge and interests related to the case to construct new knowledge. Cases facilitate active and reflective learning by exposing learners to complex situations, allowing

> them to discuss and debate courses of action and providing them with the opportunity to create and discover new ideas. (p. 29)

Cliff and Nesbitt-Curtin (2000) asserted that CBI provides instructors a vehicle to "deepen and reinforce knowledge of subject matter as it promotes the process of higher order thinking" (p. 64).

CBI can be defined as a case and its related instruction. The case is a message that is educational in nature and provides a context for subject material (Herreid, Schiller, & Herreid, 2012). The types of cases used in professional, graduate, and/or undergraduate courses fall into two general categories: analysis/issues cases or decision/dilemma cases (Herreid, 1997). Analysis/issues cases center on either contemporary or historical events and require students to explore "What happened?" An example of a historical analysis/issues case is "Bad Blood: The Case of the Tuskegee Syphilis Project" (Fourtner, Fourtner, & Herreid, 1994). In this case, the authors provided a retrospective on the Tuskegee Syphilis Project funded by the Rosenwald fund in 1929. They presented the background facts through a narrative and asked the reader to respond to study questions that involve case analysis of the facts (including the motives of those individuals involved) and of previous critiques of the case. Analysis/issues cases lend themselves well to business and law school environments. These cases supplement the course material and allow students to analyze historical or contemporary events related to the class.

Dilemma/decision cases also require students to analyze historical or contemporary events but go one step beyond by engaging students in decision-making and summarization of lessons learned. Some educators believe this type of case structure is most consistent with the scientific way of reasoning, and thus lends itself well to use in an undergraduate science curriculum (Herreid et al., 2012). The case, “To Vaccinate or Not to Vaccinate: That Is the Question,” by Caren Shapiro (2001) is a good example of a dilemma/decision case. Shapiro (2001) presents a short dialogue between a woman and her mother. The daughter is contemplating not vaccinating her four-week old infant, and the mother presents some pseudo-scientific and social reasons the child should be vaccinated. A series of study questions follows the case. These questions require the reader to separate the science from the emotional rhetoric in addressing the question, “Should the four-week-old child be vaccinated?” To provide an educated answer to this question, students should have an underlying understanding of immunology, microbiology, and epidemiology. If there are gaps in their knowledge on any of these major topics, they will need to research the facts and obtain an understanding prior to completing the assignment. Shapiro (2001) included the study questions along with the case, so that students have a framework for completing a written assignment and making a decision about the case. She also required the students to participate in an in-class discussion. This in-class discussion is unrelated to the type of case presented and is one of many ways to “teach a case” (Herreid, 1997) in a science course. Herreid (2007) classified instruction of cases into four categories (Table 2): individual assignment, lecture method, discussion approach, or small group approach. In the individual assignment approach, the faculty member will provide a student with an assignment, such as a term paper, that relates to a case. The student reads the case problem and then writes a term paper related to the solution. In this approach, the student is an active participant in the learning process and he/she directs the learning of pertinent case-related material.

Another example of the individual approach to CBI is the use of a directed case method. In this approach, students received a case study complete with questions that directed the students to the knowledge they needed to answer the case questions accurately. Herreid et al. (2012) described a directed case as one that is "designed primarily to enhance students' understanding of fundamental concepts, principles, and facts.

Table 2 Classification of Case-based Instructional Methods

Instructional Approach	Role of Student in the Learning Process	Director of Case Analysis	Examples
Individual Assignment	Active Participant	Student	Theses Term paper Directed case method
Lecture Method	Passive Recipient	Lecturer	Dialogues Debates Presentations Examples Clicker cases
Discussion Approach	Active Collaborator	Leader	Trial Symposium Public hearing
Small Group Approach	Active Collaborator	Student	Problem-based learning Team-based learning

The case usually consists of a short, dramatic scenario, accompanied by a set of directed questions that can be answered" (p. 367) by the student individually or within a group. Cliff and Nesbitt-Curtin (2000) asserted that a directed case can be used effectively in addition to traditional lecture.

The lecture approach is the classic approach to CBI and has a long history in higher education. First introduced in an undergraduate chemistry course at Harvard University in the late 1940s (Herreid, 2007), this method is widely used to provide a context for student learning. Faculty may use a real-world problem related to the lecture content as a case, for example, or they may have another lecturer join the class to debate a topic of particular interest. For the most part, the student is still a passive recipient in the learning process.

One lecture-based approach to CBI gaining popularity in undergraduate science courses is the use of Clicker Cases. Clicker Cases evolved from the traditional lecture presentation of cases to include the opportunity for students to engage actively in knowledge construction from the case (Kang, Lundeberg, Wolter, DelMas, & Herreid, 2011). A Clicker Case is "a story that includes multiple-choice questions about cases interspersed throughout the story. It is presented via a PPT [PowerPoint] presentation and designed specifically for large class presentation" (Kang et al., 2011, pp. 55-56). When students know the answer to a case question in the PPT, they push a button on their "clicker." A clicker is a student version of a personal/audience response system, which allows him/her to participate in question/answer polling.

Early studies on the use of clickers demonstrated their effectiveness at promoting active learning in large lecture classes (Guthrie & Carlin, 2004; Hake, 1998). This type of interactive technology also allows the professor to provide real-time feedback to students regarding their level of conceptual understanding (Cotner, Baepler, & Kellerman, 2008). Combining clickers, with proven case-based scenario techniques, "makes it possible to change large lecture classrooms into interactive learning environments while increasing student interest, participation, and understanding" (Kang et al., 2011, p. 56). A recent comparison study of the use of Clicker Cases across eleven undergraduate institutions concluded that their use "created dissonance, captured attention and involved students in interpreting data or making decisions" (Lundeberg et al., 2011, p. 646). Clickers have the potential to add a dimension that appeals to both kinesthetic and visual learners in a large lecture class, but that proposition has not been well studied (Baker, Matulich, & Papp, 2007).

According to Herreid (2007), the discussion-based method is a popular approach to CBI in undergraduate institutions and is used extensively in business and law school settings. Flynn and Klein (2001) defined the role of the teacher in this approach to CBI, as one of "tutor, guide, coach, or facilitator" (p. 71). In this sense, the faculty member is a skilled negotiator assisting the student with conceptual development, but not completely directing the learning process. The faculty member presents the case content to the students, but then asks the students questions to which they respond. Their role in this model becomes much more participatory than it is in the classical lecture approach to CBI. Ates (2012) suggested, "The use of cases to support a traditional lecture format compels students to deal with course material in a different manner" (p. 135). The students see the relevance of the content presented in the course and have the opportunity to engage actively with the content through the facilitated in-class discussion of the case. This discussion could be particularly beneficial to aural learners. One approach widely used with this model is the Socratic

Method. This discussion technique requires faculty members to ask questions that generate more questions for the students to answer. The students, in turn, must analyze the manner in which they derived their answer. According to Roberts and Ryrie (2011), students exposed to a Socratic method of CBI had a more contextualized view of course content.

Innovative faculty in medical schools and undergraduate science courses favor the small group approach to CBI. This method builds upon the discussion-based approach introduced previously by adding a collaborative learning environment to the case discussion. The role of the faculty member is still one of tutor/leader/facilitator, and the students are participants, but the students play a lead role in the discussion of the case. In the PBL approach, students engage with a case problem and do not receive instruction on particular content prior to working with the case. The learning in this approach is entirely self-directed (Hmelo-Silver, 2004).

Savery (2006) described PBL as a "learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (p. 12). As students work through a problem, they gather information from a variety of disciplines, share the information in collaborative groups, work with a trained facilitator to answer questions, and derive an answer as part of a group process. PBL is not an addition to a curriculum; instead, it usually is the foundation of the curriculum, and students do not receive didactic instruction. This is a popular and well-researched type of curriculum with demonstrated success at improving students' critical thinking and clinical reasoning skills (Hmelo-Silver & Barrows, 2008; Schmidt, Rotgans, & Yew, 2011;

Schmidt, Van der Molen, Winkel, & Wijnen, 2009). However, critics argue that PBL shortchanges students when it comes to coverage of content and faculty end up spending more time explaining concepts, and working with fewer students (Glew, 2003; Herreid, 2003).

In typical small group CBI, students are placed in groups, provided a case, engage in discussion facilitated by a trained leader, answer case-related questions, and derive a possible solution to the case. This approach is often aligned with the course content and used as a tool to provide a context for student learning, improve critical thinking skills (Herreid, 2007), and deepen the conceptual understanding of course content (Cliff & Nesbitt-Curtin, 2000). Students will receive a case as part of a unit in a traditional lecture course once they have been introduced to related content in the lecture. According to Herreid (2011), small group discussion is the preferred case presentation method with undergraduate science faculty and professional schools.

In the sciences, Cliff (2006) found this method effective in improving undergraduate physiology students' understanding of the complex dynamics of oxygen transport (Cliff, 2006). His study compared students' understanding of respiratory physiology concepts after exposure to a directed case study approach to that of students from a previous semester who were taught similar concepts in traditional lecture style. A weakness in the study's design is that the professors teaching the courses were not the same. One could argue that the comparison group professor was simply more skilled at explanation than was the control group professor.

Expanding on the cognitive outcomes associated with small group CBI, Murray-Nseula (2011) conducted a study with 48 undergraduate genetics students and concluded that when small group CBI is used as a supplement to traditional lectures, student perceptions of the course improved and course content coverage was not sacrificed. This improvement in student perception of a course is also reflected in earlier studies (Hudson & Buckley, 2004). In addition to improved perceptions of the course, students in Murray-Nseula's (2011) study also said that the use of case studies "strengthened their analytical, problem-solving, and critical thinking skills" (p. 82).

While previous studies concluded that CBI made a positive impact on student learning, an early study by Woody, Albrecht, and Hines (1999) claimed students expressed difficulty with meeting in groups outside of class to discuss the case topic. However, these students also indicated that group interaction in solving study questions was beneficial to their learning. Hirshfield and Koretsky (2017) suggested, "The open-ended nature of PBL activities, encourages students to become self-directed learners, learning how to teach one another and teach themselves, as the will in professional practice" (p. 2). Students who can direct their own learning often do better academically in the sciences compared to their peers (Kan'an & Osman, 2015). It stands to reason that the development of self-directed learning behaviors could influence student epistemologies. Pieschel, Stahl, and Bromme (2008) studied student learning of genetics in a biology classroom utilizing an online engagement activity. They found that self-regulated learning was associated with epistemological beliefs and prior knowledge. Students who were self-regulated were able to construct knowledge and connect it to prior knowledge. They also found a connection between epistemological beliefs and academic achievement in this setting.

Both problem-centered and cooperative learning approaches promote the active role of the student with improved academic and epistemological outcomes that may support a more gender-balanced learning experience in the science classroom. While each can stand alone as examples of learner-centered approaches to teaching, the merging of two instructional methods can be effective in producing a richer active learning environment. Smith et al. (2005) combined aspects of problem-centered learning and cooperative learning to create an Active Learning Course Framework (ALCF) for an undergraduate microbiology course at a large research institution. The framework was supported by three learning environments – the laboratory, the lecture, and online. Overall, the authors concluded that the reformed course structure was effective in improving students' understanding of the course concepts and relationship to the real world. Other efforts to transform undergraduate science courses through the combination of problem-centered learning and cooperative learning have shown similar positive outcomes for students (Gardner & Belland, 2011; Hall, 2013; Smith et al., 2005).

Like the learning environment created by Smith et al. (2005), the GAEs used to create the learner-centered organismal biology classroom explored in this study emerged conceptually from both the cooperative learning and problem-centered modes of instruction. In this study, the organismal biology course faculty members attended a Howard Hughes Medical Institute (HHMI) workshop offered by their university's Center for Teaching Excellence. The topic of the HHMI workshop emphasized transformation in teaching through the incorporation of active learning models in the undergraduate science classroom. After completing the workshop, the course faculty member and his co-instructor made a commitment to incorporate what they learned into their teaching in their organismal biology classroom. Traditionally, organismal biology at this institution was taught in a large lecture hall with one or two faculty member delivering content to over three hundred students in three, fifty-minute lectures/week. Not unlike other science faculty, these instructors faced large class sizes and space constraints predicated by the high enrollments that have become the economic reality of large research universities. Faced with these challenges they created a learning environment that aided epistemological maturation when compared to the traditional classroom model (Hall, 2013).

Hall (2013) conducted a large multi-semester study to compare shifts in student epistemologies resulting from instruction in a traditional lecture versus a learner-centered organismal biology course. Hall developed an epistemological questionnaire that explored student epistemologies in four dimensions: *Facts versus Principles; Authority versus Independence; Isolated versus Connected; and Silo-Maintenance versus Interdisciplinary Perspectives*. Her results indicated that after one semester of instruction, students taught in the learner-centered environment, student epistemological sophistication increased 6% in the *Facts versus Principles* cluster. In the *Authority versus Independence* cluster, Hall found a small (4%) improvement in student sophistication in the learner-centered course but found that student epistemologies in the teacher-centered course declined by 5%. This suggested that one semester of instruction in the learner-centered environment students became constructivist in the views of biology learning, but instruction in the traditional lecture environment led to student epistemological shift to the more naïve stance that knowledge is received passively through delivery from an authority figure. Hall found the most significant results in the *Isolated versus Connected* cluster. Students enrolled in the traditional lecture course demonstrated an 11% drop from pre-test to post-test in favorable views measured in this cluster. This result suggested that after one semester of instruction in the traditional lecture environment, fewer students believed that biological knowledge is connected to the real world. After analysis of the questions *Silo-maintenance versus Interdisciplinary Perspectives* cluster, Hall concluded that the learner-centered environment assisted the students in valuing the interdisciplinary approach.

The studies reviewed in this chapter provide insight into the role learner-centered pedagogies play in creating positive outcomes for science learners, epistemological maturation, and development of “gender neutral” (Fox Keller, 1985) classroom environments. However, gaps remain in our understanding of how gender and student epistemologies are manifested in these learner-centered contexts. This study sought to better understand these dimensions as they relate to student experiences in a learner-centered organismal biology course.

Summary

There is a call to action from policy agencies and researchers alike, to increase the number of men and women pursuing STEM careers and produce learning environments that break down the gender barriers for women in the sciences. As educators seek to develop strategies to produce future scientists and improve the cognitive, metacognitive, and socio-cultural outcomes of undergraduate science education, the research reviewed supported the need to study the factors that influence how students construct knowledge and make meaning of principles within the discipline.

In this chapter, I presented the literature that supports the notion that consideration of gender and student epistemologies in relation to learning in the sciences is important for understanding the complex way gender and epistemologies manifest in the biological sciences classroom, and potentially influence the STEM pipeline. I also examined the research that critiques teacher-centered instructional strategies, as well as reviewed learner-centered instructional models as a potential vehicle for improving biological sciences instruction at the undergraduate level. While there is a long tradition of research on epistemologies in the sciences, most studies have been conducted in physics, with only a few studies exploring the relationship between pedagogy and epistemology in the biological sciences. Of the studies that have been conducted in the biological sciences classroom, very few have focused on the potential relationship between gender and epistemology in a learner-centered biological sciences classroom. This study adds to that gap in the literature and provides an exploration of how gender and epistemology may be manifested in this pedagogical construct. The next chapter delineates the research design for this study.

Chapter 3: Methods

This chapter builds on the foundational work presented in the first two chapters and describes the mixed-methods research design and methods used to address the research questions. I begin with an overview of the study, including a description of the research questions. Next, I provide a more detailed description of the reformed learner-centered organismal biology course, the source of the data for this study. Then I describe the methods used for the quantitative and qualitative components of the study, and I conclude with a discussion of how I addressed threats to the validity and credibility of my findings.

Overview of Research Design

I conducted a secondary data analysis of a mixed methods design (Creswell & Creswell, 2018) of data collected by Hall (2013). Hall's work employed a mixed methods approach with pre-test/post-test design (Trochim & Donnelly, 2008) to compare the shifts in student epistemologies in a reformed organismal biology course taught via a traditional lecture approach versus a learner-centered approach. Hall measured epistemologies quantitatively using the MBEX I instrument (Appendix B), and she explored students' understandings of epistemologies and experiences in the course via semi-structured student interviews, classroom observations, and focus groups. Hall (2013) conducted her research under the direction of Todd J. Cooke, PhD (PI) and Edward F. Redish, PhD (Co-PI) as part of the *The Physics of Life: Interdisciplinary Education at the Introductory Level* Project funded by a NSF Division of Undergraduate Education Grant # 0919816.

Hall concluded that student epistemologies became less sophisticated after one semester of instruction in the traditional classroom environment but became more sophisticated after one semester of instruction in the learner-centered environment. Her qualitative interviews substantiated these results. While Hall's work exposed the potential benefit of the learner-centered environment in improving the epistemological sophistication of students participating in a reformed biology course, she did not include an analysis of whether the benefits of such a course might be influenced by student background variables (e.g. gender). This study built on Hall's original study to explore the dimensions of gender and epistemologies in how students experience the reformed learner-centered organismal biology classroom.

While Hall conducted her study in reformed organismal biology courses taught in both the traditional lecture format and active-learning format, I focused on data collected in the reformed, active-learning organismal biology course only. This secondary data analysis drew from two semesters (spring and fall) of pre-test and post-test MBEX I data for students who participated in the reformed learner-centered classroom for the quantitative component of the design, and it drew from student interview videos and transcripts for the qualitative component of the study. The original researcher, Kristi Lynn Hall, graciously granted me access to her original data set and I obtained permission to conduct this secondary analysis from her and the University of Maryland's Institutional Review Board.

Figure 2 provides an overview of my research design. On the left side is a description of the quantitative data instruments, sample and methods of analysis; on the right side is a description of the qualitative sources of data, the selected student interviews and methods of analysis. The parallel structure indicates that I conducted the analysis of each data stream separately, and that the results of these analyses are integrated when interpreting the results of the study. These two data streams are meant to expand the study's findings beyond what could be accomplished using only quantitative or qualitative methods. While the quantitative data provide a statistical description of students' epistemological beliefs and any change that occurred during the semester in relation to gender, the qualitative data provided students' own descriptions of epistemological beliefs and experiences in the reformed learner-centered course. These descriptions provided a richer context from which to understand the quantitative results.

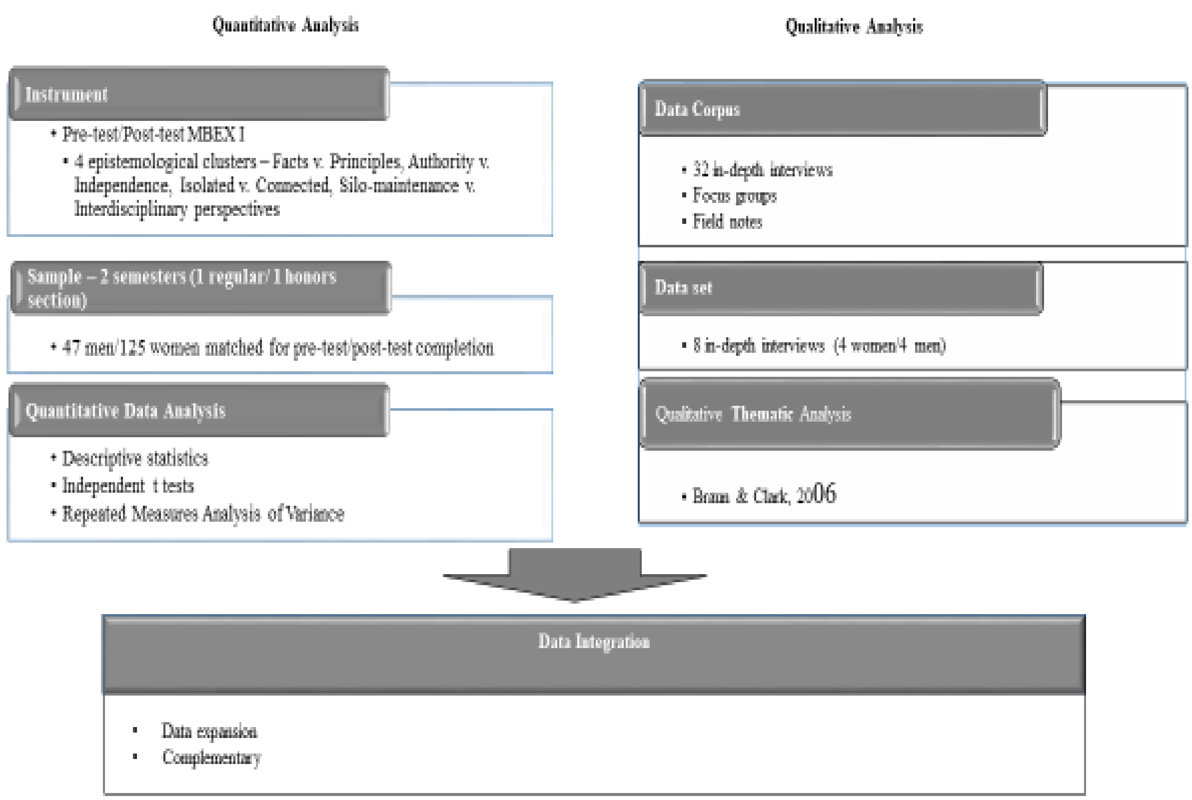

Figure 2. Mixed Methods Design (Creswell & Creswell, 2018).

Research Questions

Using these two streams of data, I explored the dimensions of gender and student epistemologies in a reformed learner-centered organismal biology course and addressed the following research questions:

1. What is the relationship between gender and student epistemologies prior to instruction in a reformed learner-centered organismal biology course?
2. What is the relationship between gender and student epistemologies after one semester of instruction in a reformed learner-centered organismal biology course?
3. What are the gender differences in the change of student epistemologies from pre-test to post-test in a reformed learner-centered organismal biology course?
4. How do men and women describe their learning experiences in a reformed learner-centered organismal biology course?

I addressed the first three research questions using quantitative analysis of MBEX I data and the last research question using qualitative thematic analysis of 8 semi-structured interviews (4 women and 4 men). I integrated these data streams in the discussion of the study findings and outcomes.

The Organismal Biology Course

To meet the needs of the future STEM workforce, policy makers have called for reform of undergraduate biology courses to include more physics and math. In alignment with policy-maker recommendations, physics and biology faculty members at a large research university collaborated to develop courses with more interdisciplinary content. One of the courses developed was a reformed organismal biology course, a third semester course for biology majors at the university. The university's online course catalog described the course as, "The diversity, structure and function of organisms as understood from the perspective of their common physicochemical principles and unique evolutionary histories." Prior to enrollment in this course, students were required to complete two introductory courses or demonstrate competency in chemistry, cell and molecular biology, and ecology and evolution. Students registered for either a regular or honors section of the course. Both sections were taught in similar format.

According to Watkins, Coffey, Redish, and Cooke (2012), the reformed organismal biology course was designed to "teach general guiding principles of biology that can be used to understand the differences and commonalities among organisms," and to "weave in mathematics, physics, and chemistry as part of an organizing framework to understand organismal diversity" (p. 010112-6). The course was not only reformed to include interdisciplinary content, but faculty also transformed the pedagogical approach to the content. The course met for fifty minutes, three times per week in a large lecture hall. "Approximately one-third of the class sessions were devoted to small-group, active engagement activities (GAEs). The remaining two-thirds were primarily lecture-based, with a small number of clicker questions supplementing instructor presentations" (Watkins et al., 2012, p. 010119).

Students registered themselves for the learner-centered organismal biology course through customary registration procedures. Students in the course attended two fifty-minute faculty-led lectures and one fifty-minute learner-centered session per week. During the learner-centered session, the students worked cooperatively on small-group, active-engagement exercises (GAEs). Students worked in groups of three to four students to addresses conceptual problems, revise biological models, and gain a deeper understanding of the principles presented during lectures. According to Watkins and Elby (2013), GAEs "centered on interdisciplinary concepts and involved a range of activities, including small-group discussions, in-class demonstrations, and data collection and synthesis" (p. 278). While two thirds of this course retained a traditional lecture format, faculty used authentic activities, demonstration, and active questioning to engage the students and guide them in connecting the new knowledge to prior knowledge. Faculty also made explicit the connections between biology, math, physics, and chemistry during lectures.

One example of a GAE is *Thermodynamics of Living Systems II: Bioenergetics, Metabolism, and Order*. This GAE was assigned to the students early in the semester. The purpose of the exercise was for students to work collaboratively in class and outside of class to meet the following learning objectives:

1. To assemble prior knowledge to construct flow diagrams of energy flow through biological systems;
2. To identify the fundamental rules governing biological E flow;
3. To translate those rules into the formalism of thermodynamics;
4. To apply thermodynamic equations for describing biological processes in class discussions and on group homework.

Students were required to complete the homework and study group work early in the week, then do an individual writing assignment in preparation for a discussion at the end of the week.

The assignment required the students to consider how biological energy flows in organisms, how energy flow is related to the First and Second Laws of Thermodynamics, and how the genome encodes molecular mechanisms that have evolved to harness these laws. The supplementary material provided in the GAE provided some background content as a baseline for student learning. To gain a rich understanding of the concepts and how they relate to one another, students had to locate other resources (e.g. lecture notes, textbook, online articles) to support their learning. This required students to collaborate and collect, organize, process, and make sense of information, then apply their acquired knowledge to a complex problem and write about it.

Watkins and Elby (2013) provided a detailed presentation of two other GAEs used in the learner-centered organismal biology course. They first provided an overview of a diffusion GAE designed to incorporate "mathematical representations and quantitative reasoning" (p. 278). This GAE required small groups of students to participate in a computer-simulated activity designed to model diffusion. Students were told to change the parameters of the simulation every twenty seconds, observe the change, and record the change on a spreadsheet. After class students were asked to construct a graph of the data and relate their graphs to the equations for Fick's First Laws, then relate Fick's Second Law to the diffusion of oxygen in different tissues and apply this knowledge to oxygen movement in the organisms with and without circulatory systems. The second GAE presented by Watkins and Elby (2013) required students to explore the mathematical relationship between surface area volume and consider the "implications and other physical challenges and opportunities organisms face. For the remainder of the class, small groups considered a hypothetical organism with a specified nutritional strategy, environment, size, and mobility characteristics; they had to discuss the design of this organism, figuring out what solutions were compatible with its form and function" (p. 279).

Through the activities promoted by the GAEs, students had opportunities to engage in learning biological content and scientific principles. These activities, which were reinforced and integrated into lectures, created a student-centered learning environment, an environment quite different for the traditional lecture hall presentation. With these reforms, faculty hoped to deepen students' understanding of organismal biology and helped students develop a more sophisticated epistemology about biology as a field of scientific study.

Methods

This study used a mixed methods design to analyze secondary data (Creswell & Creswell, 2018), including a quantitative analysis of MBEX I data and a qualitative thematic analysis of transcripts from videotaped student interviews recorded as part of Hall's (2013) study. This design allowed me to analyze the quantitative and qualitative data as distinct entities using the appropriate analysis techniques to both data streams. In this section I discuss the methods I used to conduct the quantitative and qualitative analyses of the study and provide an overview of how the design assisted my integration of the MBEX I survey and interview analyses.

Quantitative Methods

To assess student expectations for learning in the biological sciences classroom, Hall (2013) created a 32-question survey instrument to explore how student epistemologies in the reformed organismal biology course changed over time (Appendix B). The instrument was developed by Kristi Lynn under the direction of Todd J. Cooke, PhD (PI) and Edward F. Redish, PhD (Co-PI) as part of the *The Physics of Life: Interdisciplinary Education at the Introductory Level* Project funded by a NSF Division of Undergraduate Education Grant # 0919816. The instrument used questions developed specifically for learning in the biological sciences (Hall, 2013) and was adapted from a similar survey that focused on student expectations for learning in physics. On most of the questions, students indicated agreement or disagreement with a statement on a five-point Likert scale ranging from 1 equaling strongly disagree to 5 equaling strongly agree. The MBEX I survey was validated via science experts, pilot studies, classroom observations, and student validation interviews. The survey took students less than thirty minutes to complete, and pre-test values on the survey were stable across the nine semesters that it was used.

The MBEX I explored four categories of student epistemologies for learning in the biology classroom. Hall (2013) described these four categories as “clusters” (p. 94). They included: *Facts versus Principles*; *Authority versus Independence*; *Isolated versus Connected; and Silo-maintenance versus Interdisciplinary Perspectives*. Like epistemological questionnaires described in Chapter Two, the MBEX I instrument facilitated exploration of epistemologies along a continuum from naïve to expert. Hall suggested that there can be some overlap of these four clusters because the items used for each subscale are not orthogonal.

The *Facts versus Principles* cluster explored “whether biology needs to be considered as a connected, consistent framework or biology can be treated as unrelated facts” (Hall, 2013, p. 94). Students with naïve approaches to biology tended to view biology as a large set of facts but failed to see how these facts connected to larger principles and societal applications. These students tended to have a shallow learning approach, memorized facts, and failed to construct knowledge actively. Students with a more sophisticated view in this cluster saw biology as being composed of broader principles that needed to be understood, particularly though their application.

The *Authority versus Independence* cluster explored students’ view of knowledge construction in the biological sciences. Students on the more expert side of this cluster viewed knowledge from the constructivist viewpoint, where the student actively constructs knowledge. Less sophisticated students viewed knowledge development as involving the transfer of facts from the authority figure to the student.

The *Isolated versus Connected* cluster explored student beliefs about biology knowledge as being connected to real word phenomena and future uses or as being isolated with little relationship to real world applications. Students with a sophisticated viewpoint in this category viewed biological sciences content as being connected to the real world, while unsophisticated students viewed it as being unrelated and independent of experience.

The *Silo-maintenance versus Interdisciplinary Perspectives* cluster explored student views of the multi-disciplinary nature of biology. The more sophisticated students in this category found the incorporation of other disciplines, such as physics and chemistry, in the biology courses meaningful and relevant to their learning. Students with a naïve view adhered to the “traditionally held conceptual boundaries in the disciplines” (Hall, 2013, p. 95).

During week one of the experimental period, the students were asked to complete a web-based MBEX I (Appendix B) via their course’s Blackboard site. Only students who voluntarily completed this pre-test were included in the data analysis. Neither the pre-test nor post-test measures impacted a student’s course grade. At the end of the semester, students completed the post-test MBEX I (Appendix B) housed on their course Blackboard site.

The quantitative analysis in this dissertation drew from two semesters of pre-test/post-test data from Hall’s (2013) study, which yielded a dataset of 172 students (125 women / 47 men). The data set included only those students who completed both the pre-test and post-test. I used SPSS (IBM SPSS Statistics for Windows, Version 23.0) to analyze the data and used descriptive statistics and inferential statistics to explore these data. To assess the reliability of each epistemological subscale, I calculated its Cronbach alpha, a measure of internal consistency for items that comprise a scale or subscale (Tavakol & Dennick, 2011). I used independent t-tests to examine potential gender differences in pre-test and post-test scores for each subscale. To explore possible changes in student epistemologies from pre-test to post-test, I used Repeated Measures Analysis of Variance (RM-ANOVA). For all tests in this study, I set alpha at 0.05.

Qualitative Methods

For the qualitative portion of her study, Hall (2013) conducted thirty-five, hour-long, semi-structured face-to-face interviews with students to understand further how the pedagogical context produced the epistemological shifts that took place. She asked students to describe what “learning means in biology and what approaches they used to understand the material in their courses” (p. 152). She videotaped, and audio recorded over forty hours of interviews with undergraduate biology students. Initially, she coded the data “for instances where students talked, either explicitly or implicitly, about expectations” (p. 210). She also paid attention to how students described the strategies they found most useful in addressing course content.

In this study, I drew from the data corpus eight (four female/ four male) student interviews, fifty-six minutes (on average) for each. I selected these interviews because they were collected from students enrolled in the learner-centered, honors organismal biology course. In the open-ended, approximately hour-long interviews, Hall (2013) asked students to describe what it meant to learn biology and discuss various strategies they used to be successful in the course. All students interviewed were interested in pursuing biology or a related health sciences field, but not all students were at the same point in their academic career. Hall credited this to AP courses taken by students prior to admission to the institution or transferring pre-requisite courses from another institution. To guide the qualitative exploration, I purposely selected to analyze the interviews where students made explicit reference to their learning in the learner-centered course. This allowed me to find rich, contextual data to analyze in the qualitative analysis that I outline in the next section of this chapter.

I conducted qualitative thematic analysis as described by Braun and Clarke (2006) to explore the dimensions of gender and epistemology in how students describe their learning and experiences in the reformed learner-centered organismal biology course. Braun and Clarke (2006) described thematic analysis as an "accessible and theoretically-flexible approach to analyzing qualitative data" (p. 77). This process allowed me to illicit the themes that expanded the quantitative findings. I used memo writing and note taking to familiarize myself with the data, and coded attributes, emotions, values and the participants' own words to capture the reality of the students in the courses. Through an iterative and reflexive process, I examined common themes across the data set. I moved back and forth between the early and later phases of analysis to develop a rich understanding of the qualitative dataset.

As I was not involved in the collection of the original interview data, I felt it important to view the interview videos several times and re-transcribe them myself. During this process, I checked and re-checked the transcripts against the videos and original transcripts for accuracy. I created a transcript in Microsoft Word (Microsoft Office Professional Plus 2010, Version 14.0.7128.5000) that included a verbatim account of both the verbal and nonverbal interview content. In this way, I was able to capture the nuances of the dialogue along with utterances. Upon saving the interview transcript, I removed identifying information about the participant, references to other students by name, and assigned the interview transcript a pseudonym (e.g., Katy). These de-identified transcripts were housed on a personal computer under password protection. I also created an identification sheet that allowed me to connect the students' other relevant data and demographics. This sheet was kept on a separate personal computer under a different password.

I coded the data set manually using comments in Microsoft Word, highlighting, and memo writing to identify and track interesting features in the data. I found manual coding appropriate for the relatively small data set in the study. As I worked through the analysis, I remained open to coding data that didn't fit a prescribed template. Fereday and Muir-Cochrane (2006) described this as "recognizing (seeing) an important moment and encoding it (seeing it as something) prior to a process of interpretation" (p. 83). As I was not performing a content analysis or grounded theory, I coded data that I found relevant to understanding how men and women described "what counts as learning" and "what kinds of learning and understanding are rewarded in their courses" (Watkins & Elby, 2013).

I included memos in my research journal to track my thoughts and assumptions on the text as I coded. I often used descriptive, thematic, analytic codes looking at attribute, value, expressed emotion, and students' words as a coding constructs to derive potential themes and sub-themes from the data. I also looked for times in which the students referenced their learning in the course. Initially, I developed fourteen codes that represented trends in the data set. After refining and collapsing the codes, I categorized the data. Next, I created a concept map (Appendix C) and chose data excerpts that represented the themes and sub-themes that highlighted how gender and epistemologies influenced the experiences of men and women in the course.

Threats to Validity and Credibility

Given that the data for this study were drawn from a previous study, the data were subject to the original threats to validity and credibility, and any new threats raised by my use of these data. Hall (2013) controlled significant threats to internal validity through her research design. Studies of this kind face the potential threat of selection bias. Hall controlled for this threat by not identifying which sections of the organismal biology course were taught from the learner-centered approach or the traditional lecture approach. Students registered for the sections without knowing which type of pedagogy they would receive and, thus, were not biased in their course selection.

Instructors can have very different lecture styles. Having two sections with different instructors potentially increases the risk that any outcome is influenced by the instructor (instructor bias), rather than the pedagogical context. To control for instructor bias in the design, Hall paired instructor sections (i.e., a traditional lecture format with the reform format). While this design still posed the threat of contamination, where the instructor incorporates aspects of the reformed pedagogy into the traditional pedagogy, Hall did not observe this happening in her study. Moreover, in the subset of data that I use for this analysis, the same instructor taught both organismal biology courses, further reducing any concerns about instructor bias.

Significant threats to internal validity in the quantitative study were controlled by matching the data to pre-test and post-test scores for students who completed both tests during data collection. I checked statistically the reliability of measures used in the analyses, and I checked statistically to ensure that my analytic methods met the assumptions of the statistical techniques used in the study. However, I did not have a full complement of control variables available for the analysis, such as course grade or prior courses taken.

For the qualitative portion of the study, the fact that I did not collect the original interview data was a threat to the credibility of my analysis. I relied on the good data management practices of the original researcher, so there could be nuances that I missed in the review of the videos and interview transcripts. Another threat to credibility is the solo-nature of my analysis. I alone coded and identified the themes in the data, which allowed me to maintain internal consistency during analysis, but did not allow for more fine-grained reflection by multiple researchers to gain a broader view of the data set.

Summary

The purpose of the study was to explore the dimensions of gender and epistemology in how students experienced a reformed, learner-centered undergraduate organismal biology course. Understanding how reformed curricula and new approaches to instruction influence learning and beliefs of different student populations is an important consideration for educators who seek to improve student learning in their courses and improve the diversity of the STEM professions. This chapter described how my methodology was designed to achieve that purpose. It provided an overview of the research design, including the research questions. It described the organismal biology course, which was the source of data for the study, and provided more details about the quantitative and qualitative methods. This chapter also addressed concerns about potential threats to the validity and credibility of the study's findings. Chapter 4 presents the results of both the quantitative results and qualitative findings.

Chapter 4: Results

This study used a mixed methods design (Creswell & Creswell, 2018) to analyze secondary data. The data set consisted of MBEX I pre-test/post-test survey data and semi-structured student interviews drawn from the MBEX I development study conducted by Hall (2013). In this chapter, I discuss the results of the quantitative statistical analysis and the qualitative thematic analysis. The first section of this chapter addresses the quantitative results that were obtained through independent t-tests and repeated measures analysis of variance (RM-ANOVA). These analyses explored the relationship between student epistemologies about science (dependent variable) and gender (independent variable) for students who participated in a learner-centered pedagogical context. In the second section of this chapter, I present the findings of the qualitative thematic analysis of student interviews that allowed me to illicit themes and expand upon the quantitative results for this student population. These analyses were integrated to identify important outcomes that suggested the course was successful at shifting student epistemology in certain categories, but that gender and epistemological sophistication may have influenced how students experienced the course.

Quantitative Results

This study drew from two semesters (fall and spring) of a learner-centered organismal biology course at a large research university. The fall semester course was an honors only course with a total enrollment of 80 students. The spring semester course was a general student course with a total enrollment of 147 students. The same instructor taught both sections with the same instructional approach. When conducting the active learning exercises, the large spring section was broken down into two smaller sections of no more than 75 students to facilitate the GAE. I included results from 172 students (125 women and 47 men) who completed both the pre-test and the post-test surveys. In the sections that follow, I describe the sample of students who participated in the study. I then present the results of the analyses for the first two research questions (i.e., whether there were gender differences in pre-test and post-test scores for each epistemological cluster), followed by the third research question (i.e., whether there were gender differences in any changes in epistemological understanding between the pre-test and post-test scores).

Sample

The sample characteristics of the students in the data set are summarized in Table 3, which provides information about the gender and grade breakdown of students who participated in the study. Nearly two thirds of the students were women. Roughly four fifths or more of students were either first-year students or sophomores. Student class (e.g. freshmen) is defined by a students' credit level rather than matriculation date.

Table 3 Student Demographics

N (%)	Men (36%)	Women (64%)
Freshmen	13%	71%
Sophomore	64%	21%
Junior	18%	5%
Senior	5%	3%

Gender Differences in Pre-test and Post-test Scores

The research questions, “What is the relationship between gender and student epistemologies prior to instruction in a reformed learner-centered organismal biology course?” and “What is the relationship between gender and student epistemologies after one semester of instruction in a reformed learner-centered organismal biology course?” were addressed using independent t-tests in IBM SPSS®. I explored the relationship between gender and level of sophistication of the students’ epistemological stance at pre-test and post-test for the MBEX instrument as a whole and for each of the four epistemological clusters (*Facts versus Principles, Authority versus Independence, Isolated versus Connected, and Silo-Maintenance versus Independence*). The independent *t*-test allowed for efficient analysis when exploring the difference between two nominal variables (men and women) with one continuous measurement variable (mean on pre-test MBEX I and mean on post-test MBEX I)

Whole MBEX Instrument. The whole MBEX instrument consisted of all MBEX I questions without question 24, which was designed by the original researcher to verify that students were paying attention while answering the instrument questions. I found the pre-test subscale ($\alpha = .85$) and post-test subscale ($\alpha = .75$) to be reasonably reliable for the purposes of this study.[1] Each question had a possible mean score range of 1 to 5, with 1 being the least sophisticated (e.g., biology consists of facts to be memorized) and 5 being the most sophisticated (e.g., biological

[1] Cronbach’s alpha is a measure of internal consistency of items used in a scale. While higher values are thought to reflect greater reliability, scales with alphas as low as .50 have been found to still be a valid and useful measure of an underlying construct (Schmitt, 1966).

knowledge is grounded in principles). Table 4 presents the results of the independent *t*-tests for the whole MBEX I Instrument. The first two rows report gender differences by pre-test scores and the second two rows report gender differences by post-test scores. As displayed in Table 4, men (M = 3.34, SD = .33) and women (M = 3.36, SD = .34) did not statistically differ on levels of epistemological sophistication at pre-test, *t* (170) = -.415, p = .68. At post-test, there was also no evidence of differences, *t* (110) = -1.01, p = .314 between men (M = 3.41, SD = .28) and women (M = 3.47, SD = .38). The effect size for the pre-test analysis (d = .06) and the effect size for the post-test analysis (d = .17) are consistent with a "no difference" conclusion for these results. Both effect sizes are below Cohen's (1988) convention for a small effect (d = .20). Both men (.07) and women (.11) made slight gains in their level of sophistication related to this epistemological cluster. However, the independent t-test does not examine whether these differences are statistically significant (see the results of the repeated measures analysis of variance for statistical significance).

Table 4 Results of t-tests and Descriptive Statistics for Total MBEX Instrument

	Gender				
	Men N= 47	Women N = 125	95% CI for Mean Difference	*T*	*Df*
Pre-test	3.34 (.33)	3.36 (.34)	-.415, .679	-.415	170
Post-test	3.41 (.28)	3.47 (.38)	-.162, .053	-1.01	110

Note. Standard Deviations appear in parentheses below means. Levene's Test for Equality of Variances was significant (*F* = 5.37, *p* = .02) for post-test scores indicating unequal variances. As a result, the degrees of freedom were adjusted from 170 to 99 to test for statistical significance.

There were no statistically significant differences in scores between men and women at the beginning of the course, and no statistically significant differences in scores between men and women at the end of the course. Scores for both men and women shifted slightly upward, .08 and .11 respectively, after one semester of instruction in the active learning environment on the whole MBEX instrument.

Facts versus Principles. The *Facts versus Principles* subscale consisted of eleven MBEX I questions (See Appendix D for a list of items by subscale). I found the pre-test subscale (α = .62) and post-test subscale (α = .68) to be reasonably reliable for the purposes of this study.[2] Each question had a possible mean score range of 1 to 5, with 1 being the least favorable (e.g., biology consists of facts to be memorized) and 5 being the most favorable (e.g., biological knowledge is grounded in principles).

Table 5 presents the results of the independent t-tests for the *Facts versus Principles* cluster. The first two rows report gender differences by pre-test scores and the second two rows report gender differences by post-test scores. As displayed in Table 5, men (M = 3.43, SD = .48) and women (M = 3.47, SD = .45) did not statistically differ on levels of epistemological sophistication at pre-test, t (170) =-.55, p = .58. At post-test, there was also no evidence of differences, t (170) = -1.19, p = .24 between men (M = 3.54, SD = .46) and women (M = 3.65, SD = .51). The effect size for the pre-test analysis (d = .09) was consistent with a no significant effect conclusion. The effect size for the post-test analysis (d = .22) was consistent with a

[2] Cronbach's alpha is a measure of internal consistency of items used in a scale. While higher values are thought to reflect greater reliability, scales with alphas as low as .50 have been found to still be a valid and useful measure of an underlying construct (Schmitt, 1966).

“small effect size” conclusion for these results. Both effect sizes are at or below Cohen’s (1988) convention for a small effect (d = .20). Both men (.11) and women (.17) made slight gains in their level of sophistication related to this epistemological cluster (see the results of the repeated measures analysis of variance for statistical significance).

Table 5 Results of t-tests and Descriptive Statistics for Facts versus Principles Cluster by Gender

	Gender				
	Men N= 47	Women N = 125	95% CI for Mean Difference	*T*	*Df*
Pre-test	3.43 (.48)	3.47 (.45)	-.198, .112	-.55	170
Post-test	3.54 (.46)	3.65 (.51)	-.269, .067	-1.19	170

Note. Standard Deviations appear in parentheses below means.

There were no statistically significant differences in scores between men and women at the beginning of the course, and no statistically significant differences between men and women in scores at the end of the course. Scores for both men and women shifted only slightly upward after one semester of instruction in the active learning environment in this cluster.

Authority versus Independence. The *Authority versus Independence* subscale consisted of thirteen MBEX I questions (See Appendix D for a list of items by subscale). I found the pre-test (α = .52) subscale and post-test subscales (α = .62) to be, again, reasonably reliable[3] for the purposes of this study. Each question had a

[3] Cronbach’s alpha is a measure of internal consistency of items used in a scale. While higher values are thought to reflect greater reliability, scales with alphas as low as .50 have been found to still be a valid and useful measure of an underlying construct (Schmitt, 1966).

possible mean score range of 1 to 5, with 1 being the least sophisticated (e.g., knowledge is acquired passively from an authority figure) and 5 being the most sophisticated (e.g., knowledge is constructed independently).

Table 6 presents the results of the independent *t*-tests for the *Authority versus Independence* cluster. The first two rows report gender differences by pre-test scores and the second two rows report gender differences by post-test scores. As displayed in Table 6, men ($M = 3.19$, $SD = .39$) and women ($M = 3.29$, $SD = .45$) did not differ statistically on the pre-test scores. However, men ($M= 3.31$, $SD = .38$) and women ($M = 3.45$, $SD = .46$) did differ statistically on the post-test score, $t\ (99) = -1.99$, $p = .05$. Both the effect size for the pre-test ($d =.23$) and post-test ($d = .33$) were at or above Cohen's (1988) convention for a small effect ($d = .20$), confirming that there was some difference between men and women in the post-test scores on the *Authority versus Independence* cluster.

Table 6 Results of t-tests and Descriptive Statistics for Authority versus Independence Cluster by Gender

	Gender				
	Men N= 47	Women N = 125	95% CI for Mean Difference	*T*	*Df*
Pre-test	3.19 (.39)	3.29 (.45)	-.250, .042	-1.4	170
Post-test	3.31 (.38)	3.45 (.46)	-.273, .000	-1.99*	99

Note. * = $p < .05$. Standard Deviations appear in parentheses below means. Levene's Test for Equality of Variances was significant ($F = 4.79$, $p = .03$) for post-test scores indicating unequal variances. As a result, the degrees of freedom were adjusted from 170 to 99 to test for statistical significance.

There were no statistically significant differences in scores between men and women at the beginning of the course, but a statistically significant difference between men and women in scores at the end of the course. Scores for both men (.12) and women (.16) shifted upward after one semester of instruction in the active learning environment in this cluster.

Isolated versus Connected. The *Isolated versus Connected* cluster consisted of five MBEX I questions (See Appendix C for a list of items by subscale). Each question had a possible mean score range of 1 to 5, with1 being the least sophisticated (e.g., biological principles are isolated from real world phenomena) and 5 being the most sophisticated (e.g., biological principles are connected to the real world and future applications). The reliability scores for the pre-test (α =.63) and post-test subscales (α = .59) were sufficient[4] for the purposes of this study.

Table 7 presents the results of the independent t-tests for the *Isolated versus Connected* cluster. The first two rows report gender differences by pre-test scores and the second two rows report gender differences by post-test scores. As displayed in Table 7, men (M = 3.74, SD =.55) and women (M = 3.64, SD = .63) did not differ statistically on levels of epistemological sophistication at pre-test, $t(170) = 1.00$, p = .32., and men (M = 3.68, SD = .62) and women (M = 3.54, SD = .71) did not differ statistically on levels of epistemological sophistication at post-test, $t(170) = 1.23$, p =

[4] Cronbach's alpha is a measure of internal consistency of items used in a scale. While higher values are thought to reflect greater reliability, scales with alphas as low as .50 have been found to still be a valid and useful measure of an underlying construct (Schmitt, 1966).

.22. There appeared to be a slight negative trend in this cluster (see the results of the repeated measures analysis of variance for statistical significance).

There were no statistical differences in scores between men and women at the beginning of the course, and no statistical differences in scores between men and women at the end of the course in this cluster. Scores for both men and women shifted downward, slightly, .06 and .10 respectively, after one semester of instruction. The effect size for the pre-test (*d* =.19) was below Cohen's (1988) convention for a small effect and the effect size for the post-test (*d* = .21) was above Cohen's (1988) convention for a small effect (*d* = .20), suggesting that there was some difference between men and women in the post-test scores on the *Isolated versus Connected* cluster.

Table 7 Results of t-tests and Descriptive Statistics for Isolated versus Connected Cluster by Gender

	Gender				
	Men N= 47	Women N = 125	95% CI for Mean Difference	*T*	*Df*
Pre-test	3.74 (.55)	3.64 (.63)	-.102, .312	1.0	170
Post-test	3.68 (.62)	3.54 (.71)	-.099, .377	1.23	170

Note. Standard Deviations appear in parentheses below means.

Silo-maintenance versus Interdisciplinary Perspectives. The *Silo-maintenance versus Interdisciplinary Perspectives* cluster consisted of nine items (See Appendix D for a list of items by subscale). I found the pre-test (α = .65) and post-test subscales (α = .63) to be reliable for the purposes of the study. Each question had a possible mean score range of 1 to 5, with 1 being the least sophisticated (e.g., biology knowledge is isolated from other disciplines) and 5 being the most sophisticated (e.g., biology is connected to other disciplines).

Table 8 presents the results of the independent t-tests for the *Isolated versus Connected* cluster. The first two rows report gender differences by pre-test scores and the second two rows report gender differences by post-test scores. As displayed in Table 8, men (M = 3.25, SD = .61) and women (M = 3.26, SD = .51) did not differ statistically on levels of epistemological sophistication at pre-test, t (170) = -.09, p = .93. There was also no statistically significant difference, t (170) = -.62, p = .53, between men (M = 3.31, SD = .56) and women (M = 3.36, SD = .50) at post-test. Scores for men and women increased between the pre-test and post-test (.06 for men and .10 for women, see the results of the repeated measures analysis of variance for statistical significance). The effect size for the pre-test analysis (d = .02) and the effect size for the post-test analysis (d = .09) are consistent with a "no difference" conclusion for these results.

Table 8 Results of t-tests and Descriptive Statistics for Silo-maintenance versus Interdisciplinary Perspectives by Gender

	Gender				
	Men N= 47	Women N = 125	95% CI for Mean Difference	*T*	*Df*
Pre-test	3.25 (.61)	3.26 (.51)	-.189 .173	.93	170
Post-test	3.31 (.56)	3.36 (.50)	-.231, .120	.53	170

Note. Standard Deviations appear in parentheses below means.

There were no statistical differences in scores between men and women at the beginning of the course, and no statistical differences between men and women in scores at the end of the course in this cluster. Scores for both men and women had a positive trend over time for this cluster.

Gender Differences in Epistemological Shifts

To address the research question, "What are the gender differences in the change of student epistemologies from pre-test to post-test in a reformed learner-centered organismal biology course?" I conducted an RM-ANOVA in IBM SPSS®. I explored the interaction of gender with time on the mean student epistemological stance from pre-test to post-test and conducted this analysis for each of the four epistemological clusters. RM-ANOVA offers a robust method to compare mean scores where the dependent variable is continuous and the independent variables (gender and time) are categorical. For this analysis, time (pre-test and post-test) was coded as the within-subjects factor and the independent variable, gender (male and female) was assigned to the between-subjects factor. This allowed me to explore and interpret any statistical differences in subscale scores across time for all participants and any statistical gender differences across time for men and women (i.e., was the change in scores for men different than the change in scores for women).

Total MBEX Instrument. On the total MBEX instrument there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality ($p < .05$). Both the variances ($p > .05$) and covariances ($p > .05$) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05).

These results indicated that the data met the assumptions for conducting an RM-ANOVA. Table 9 reports the results. The first row reports the results for all students (main effect of time) while the second row compares results for men and women (interaction effect). As reported in Table 5, there was a statistically significant main effect of time, F (1, 170) = 11.86, p = .00, n^2 = .09, but there was no statistically significant interaction between time and gender for the *MBEX I Instrument*, *F (1, 170)* = 0.353, p = 0.55, n^2 = .00.

Table 9 Repeated Measures Analysis of Variance for Total MBEX I Instrument

Effect	*MS*	*Df*	*F*	*p*
Time	.538	1	11.89	.001*
Time X Gender	.016	1	.353	.553
Error	7.68	170		

Note. * = $p < .05$

The significant difference in time for the MBEX I instrument from pre-test to post-test indicated that both men and women became more sophisticated in their understanding of biology after one semester of instruction in the learner-centered classroom. As indicated in *Figure 3*, the slopes for both men and women slightly increased.

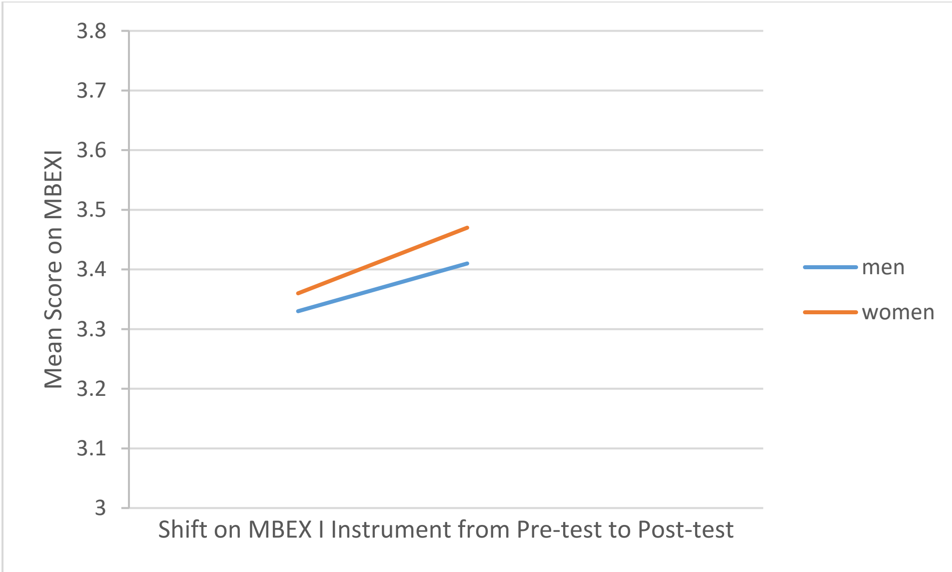

Figure 3. Results of the Impact of Gender on MBEX I Mean Scores Over Time

Facts versus Principles. In the *Facts versus Principles* cluster there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality ($p < .05$). Both the variances ($p > .05$) and covariances ($p > .05$) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). These results indicated that the data met the assumptions for conducting an RM-ANOVA. Table 10 reports the results. The first row reports the results for all students (main effect of time) while the second row compares results for men and women (interaction effect). As reported in Table 10, there was a statistically significant main effect of time, F (1, 170) = 15.51, p = .00, n^2 = .08, but there was no statistically significant interaction between time and gender for the *Facts versus Principles* cluster, F *(1, 170)* = 0.628, p = 0.429, n^2 = .00.

Table 10 Repeated Measures Analysis of Variance for Facts versus Principles Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	1.44	1	15.51	.00*
Time X Gender	.058	1	.628	.429
Error	.093	170		

Note. * = *p* < .05.

The significant difference in time for *Facts versus Principles* from pre-test to post-test indicated that both men and women became more sophisticated in their understanding of biology as being composed of broader principles after one semester of instruction in the learner-centered classroom (Figure 4).

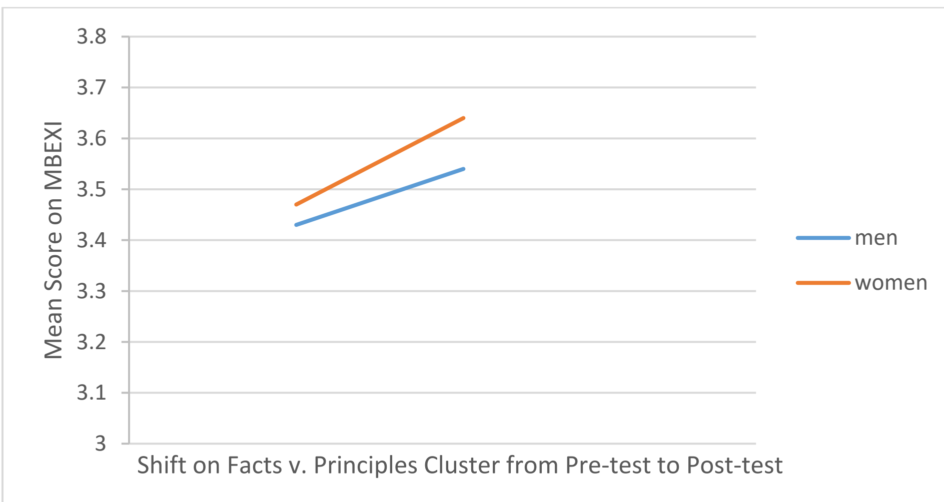

Figure 4. Results of Gender Difference on MBEX I Mean Scores Over Time for the Facts versus Principles Cluster.

Authority versus Independence. In the *Authority versus Independence* cluster there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality (p < .05). Both the variances (p > .05) and covariances (p > .05) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). As with the *Facts versus Principles* cluster, these results indicated that the data met the assumptions for conducting an RM-ANOVA.

Table 11 reports the results of the RM-ANOVA for the *Authority versus Independence* cluster. Again, the first row, reports whether there is a change in scores for all students between the pre-test and post-test, while the second row reports whether the change in scores during this period was the same for men and women. As displayed in Table 11, there was a statistically significant result of time for *Authority versus Independence* cluster, F (1, 170) = 16.46, p =.00, n^2 = .00, but no statistical difference in the main effect for the gender interaction, F (1,170) =.230, p = .63, n^2 = .09.

Table 11 Results of Gender Difference MBEX I Mean Scores Over Time for the Facts versus Principles Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	*1.32*	*1*	*16.46*	*.00**
Time X Gender	*.019*	*1*	*.230*	*.632*
Error	*.298*	*170*		

Note. * = p <.05.

This result suggested that intentional instruction in constructing knowledge in the active learning environment led to epistemological growth from pre-test to post-test in this cluster for both men and women as shown in *Figure 5*.

Figure 5. Results of Gender Difference on MBEX I Mean Scores Over Time for the Authority versus Independence Cluster.

Isolated versus Connected. In the *Isolated versus Connected* cluster there were no outliers as assessed by box plot distributions and the data were distributed normally as assessed by Shapiro-Wilk's test of normality (p < .05). Both the variances (p > .05) and covariances (p > .05) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). As these results indicate, the data satisfied the assumptions of RM-ANOVA.

Table 12 reports the results of the RM-ANOVA for the *Isolated versus Connected* cluster. Again, the first row, reports whether there is a change in scores for all students between the pre-test and post-test, while the second row reports whether the change in scores during this period was the same for men and women. As displayed in Table 12, there was not a statistically significant difference in time for men and women from pre-test to post-test, F (1, 170) = 2.56, p =.10, n^2 = .02, and no statistically significant interaction between time and gender, F (1, 170) =.148, p =.701, n^2 = .00. While the direction of change indicated that both men and women became somewhat less sophisticated in their viewpoint of biology's relationship to the broader world after one semester of instruction in the reformed, learner-centered organismal biology course, the result was not statistically significant.

Table 12 Repeated Measures Analysis of Variance for Isolated versus Connected Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	.481	1	2.57	.110
Time X Gender	.028	1	.148	.701
Error	31.63	170		

As shown in *Figure 6*, scores declined slightly for both men and women for this cluster, but not to the extent that the decline was statistically significant.

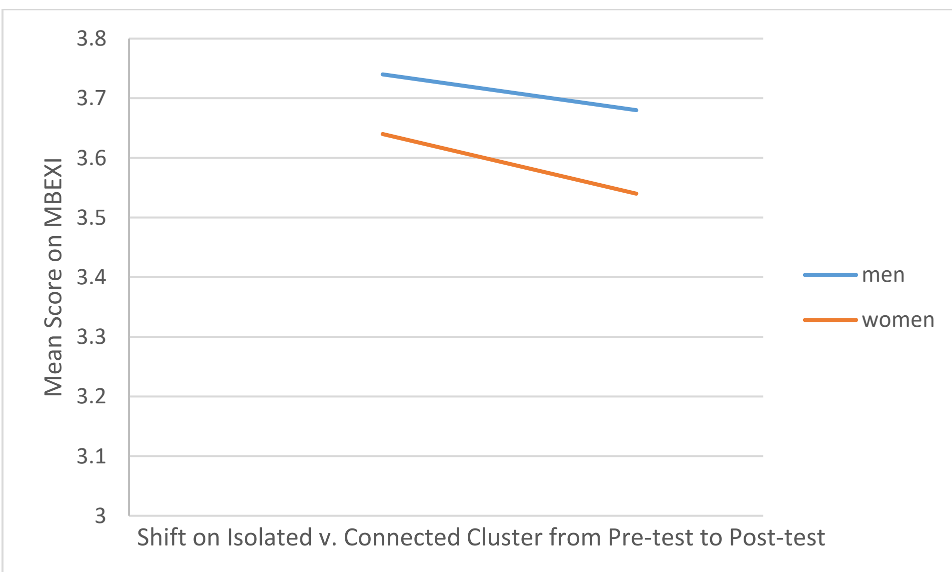

Figure 6. Results of Gender Difference on MBEX I Scores Over Time in the Isolated versus Connected Cluster

Silo-maintenance versus Interdisciplinary Perspectives. In the *Silo-maintenance versus Interdisciplinary Perspectives* cluster there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality ($p < .05$). Both the variances ($p > .05$) and covariances ($p > .05$) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). As with the other clusters, the data for the *Silo-maintenance versus Interdisciplinary Perspectives* cluster satisfied the assumptions for conducting an RM-ANOVA.

Table 13 reports the results of the RM-ANOVA for the *Silo-maintenance versus Interdisciplinary Perspectives*. Again, the first row, reports whether there is a change in scores for all students between the pre-test and post-test, while the second row reports whether the change in scores during this period was the same for men and women. There was no statistical difference by time, F (1, 170) = 3.66, p = 0.06, n^2 = .02, or gender in the scores of men and women, F (1, 170) = .317, p = 0.574, n^2 = .00, for this cluster. While scores increased between the pre-test and the post-test in this cluster, the result was not statistically significant using a .05 criterion.

Table 13 Repeated Measures Analysis of Variance for Silo-maintenance versus Interdisciplinary Perspectives Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	.441	1	3.66	.057
Time X Gender	.038	1	.317	.574
Error	20.45	170		

As shown in *Figure 7*, the scores of men and women increased from pre-test to post-test, though not quite to the extent that the increase was statistically significant.

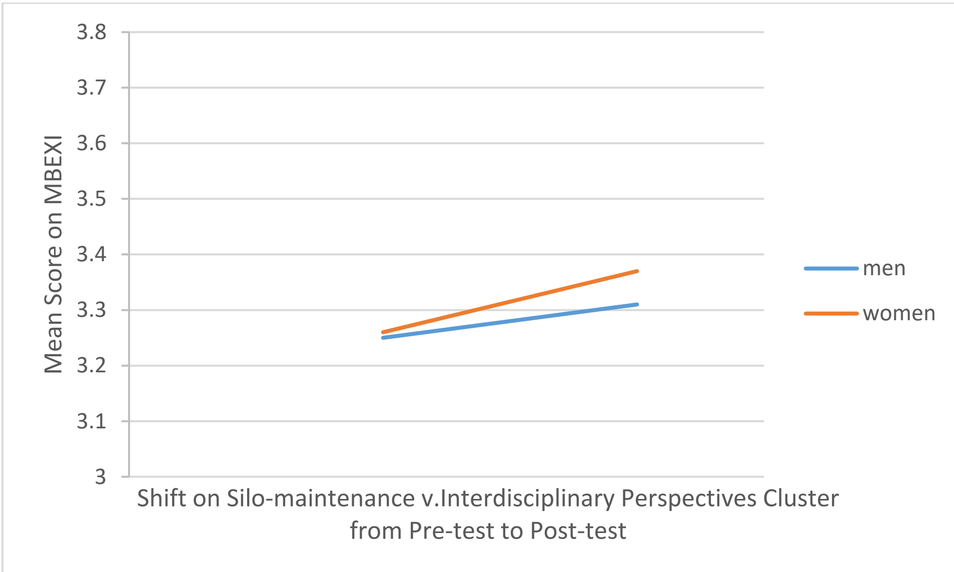

Figure 7. Results of Gender Difference on MBEX I Mean Score Over Time for the Silo-maintenance versus Interdisciplinary Perspectives Cluster.

Summary of Quantitative Results

The quantitative results indicated there were no significant differences between women's and men's MBEX I scores at pre-test or post-test on the overall MBEX I instrument or in the *Facts versus Principles, Isolated versus Connected*, and *Silo-maintenance versus Interdisciplinary Perspectives* clusters. There was a significant difference between men and women at post-test in the *Authority versus Independence* cluster. In this cluster, women shifted positively at a slightly higher slope than their male counterparts in the course, though the difference in slopes was not statistically significant.

Both men and women demonstrated significant positive shifts on the overall MBEX I instrument and in the *Facts versus Principles* and *Authority versus Independence* clusters after one semester of instruction in the reformed learner-centered organismal biology course. This result demonstrated that the active learning pedagogy in the learner-centered course was successful in shifting students toward a more sophisticated epistemological stance in that biological science knowledge is based on principles rather than consisting of isolated facts and that knowledge construction is appropriate in studying biology rather than memorizing facts. I expected this result in this category given that active learning environments with collaborative group work were intentionally included in the course design to ensure students developed a sense of shared meaning making and knowledge construction.

The next section of this chapter presents the qualitative findings for the study. The inclusion of qualitative analysis here was meant to expand the quantitative results and aid in the development of a better understanding of the students' experiences in the reformed learner-centered course.

Qualitative Findings

A main aim of this study was to gain an understanding of how men and women experience the learner-centered organismal biology course and examine potential similarities and/or differences in the patterns of how they describe these experiences. Qualitative thematic analysis of student interviews provided the opportunity to expand the quantitative findings.

Participant Characteristics

Eight student interviews (four men/four women) were selected from Hall's (2013) data corpus as part of the qualitative analysis. I selected these participants because they were interviewed during the fall semester in which the quantitative data for this analysis were collected and all participants were interviewed after they had exposure to the active learning environment. Students selected for the interviews were in their first or second year and all were biology majors (Table 14). The average length of the interviews was fifty-six minutes, representing close to eight hours of interview transcripts.

Table 14 Participant Demographics

Student (Pseudonym)	Gender	Major	Rank
Alex	Male	Biology & Psychology	Sophomore
Allison	Female	Biology	Sophomore
Ellen	Female	Biology	Freshmen
Joseph	Male	Biology	Freshmen
Katy	Female	Biology & Animal Science	Freshmen
Leah	Female	Biology	Sophomore
Lee	Male	Biology	Freshmen
Michael	Male	Biology & Math	Sophomore

Findings and Interpretation

The qualitative analysis revealed two key findings consisting of themes and associated sub-themes related to how men and women experienced the reformed course content and learner-centered classroom environment. Table 15 presents the key findings, themes, subthemes, and example of the codes.

Gender influenced the perception of the value of the inclusion of other disciplines in the reformed course content. The first finding suggested that there was a difference in how women and men perceived the value of including math, chemistry, and physics in the learner-centered organismal biology course.

This finding emerged from two opposed themes; one where women resisted the inclusion of math, physics, and chemistry in the reformed course compared to men who seemed to welcome the inclusion of this quantitative content in the reformed course.

Table 15 Key Findings, Themes, Sub-Themes, and Associated Codes

Key Findings	Themes	Sub- Themes	Codes
Gender influenced the perception of value of the inclusion of other disciplines in the reformed course content.	Math, physics, chemistry don't play a role in learning biology for women	"I hate physics" physics is "yucky" "Can't summarize biology with numbers and letters"	QUANT +
	Math, physics, chemistry play a role in learning biology for men	"Stuff in nature applies to math" Thermodynamics content "very helpful" "Math kind of guy"	QUANT -
	Outlier man	"I don't really like math	
Level of epistemological sophistication influenced student response to the active learning environment for both men and women.	Learning in biology is enhanced through active learning for students with sophisticated frames	Less stressful learning environment Made you think Thinking in new ways	ACKN +
	Active learning in biology is challenging for novice learners	More stressful Frustration	ACKN –

Math, physics, chemistry don't play a role in learning biology for women. Women interviewed in this study did not find value in the inclusion of math, physics, and chemistry content in the reformed course. These women expressed viewpoints that suggested a belief that biology should be separate from these more quantitative disciplines. Marra and Palmer (2008) suggested that a main aim of higher education is to design a pedagogical intervention and classroom environment that "helps students to think in integrated ways and see connections between apparently disparate information sources rather than focused in domain silos" (p. 115). While inclusion of this content was purposefully designed to allow students to see the interdisciplinary nature of biology, women may have remained resistant to this curricular change.

All of the women interviewed expressed distaste for the inclusion of math and physics in the course, suggesting that prevalent gender-math stereotypes may have impacted their view of the value of the inclusion of this content. Women used words like "yucky" to describe their view of quantitative subject matter and directly referenced the inclusion of equations with variables and numbers as being unnecessary to their learning. Belenky et al. (1986) would have described their desire for disciplinary isolation as subjective (knowledge is a good/bad proposition) on their scale of epistemological sophistication. From another developmental epistemological stance, Muis, Trevors, Duffy, Ranellucci, and Foy (2015) would categorize the women's epistemic stance as absolutist – a stance where knowledge is certain, unchanging, and delivered by an authority figure. Neither of these epistemic beliefs align with the call to action.

One young woman, Leah, stated: “Like, I hate physics, because I feel like it’s not applicable, so for me, I just like learning something that is real…it’s going on.” Leah’s implication here is that physics is not tangible or applicable to the real world. She preferred to learn things she described as “real” and potentially relevant to the world at large. Here she exhibited a more complex epistemic stance toward biology knowledge as being “real”, but demonstrated a more novice epistemic stance toward physics as “not applicable”. This is consistent with the work of Muis et al. (2015) who found that students exhibited different levels of epistemological sophistication in different disciplines at the same time across all age groups. Hammer and Elby (2003) also concluded that students can deploy varying epistemological resources in response to different classroom environments.

Wang and Degol (2017) suggested, “Abundant cultural stereotypes lead women to believe that math-intensive careers are inconsistent with their desire to work with people” (p. 125). Leah chose to depict physics as something intangible and unreal, a content not worthy of inclusion in biology, perhaps because her sociocultural development created a gendered view of the relation of quantitative subjects to her long-term career goals and thus may have shaped a negative association with the subject. Wang and Degol (2017) argued, “The stereotype in Western culture that math and science are male domains is so pervasive that children as young as six subscribe to it” (p. 128). They asserted further, “the gender experiences that girls have with math and science likely send the message that math and science are male domains” (p. 128).

According to Nosek et al. (2002), “Consciously expressed preferences for math may be viewed by the individual (and others) to be a function of his or her own choosing (e.g., “I just don’t like math”) when, in fact, those preferences may be traced to implicit social group identity and implicit knowledge of the attributes associated with the group” (p. 50). Marra and Palmer (2008) suggested further that when students experience a pedagogical intervention, the student’s “microsystem” (p. 110) interacts with the disciplinary domains and impact epistemic beliefs. Those beliefs that are “more proximal to the individual will exert more direct influence” (p. 111) on the learner. In this sense, Leah’s microsystem (e.g. identity as a biology student) was embedded in a larger socio-cultural context that emphasized math/physics superiority of men over women. The inclusion of physics and math content in the course was juxtaposed to these epistemic beliefs and made her resistant to faculty efforts to produce epistemological change.

Other women expressed similar views to Leah’s. Katy stated, “Uh…I was completely lost with the physics stuff,” and later in the same interview she reasserted: “I think that biology is just- it’s supposed to be tangible, perceivable, and to put that in terms of letters and variables, it is just very unappealing to me.” Ellen also felt that “You can’t really summarize all of biology with numbers and letters” and that “Math in general to me should stay, like its own thing.” She later claimed that the reason students chose to pursue a biological sciences degree was to avoid math: “I feel that bio majors tend to shy away from math…and people who don’t like math will maybe like biology more, because there is less math in it.” These women’s discomfort with the inclusion of math in the course curriculum could stem from situations where negative stereotypes about women and math ability were affirmed by socio-cultural constructs (Tomasetto & Appoloni, 2013).

This gendered pattern may have made it difficult for the women in the reformed course to find value in math's inclusion and resistant to the change the professors were attempting to produce. Wang and Degol (2017) related this type resistance to the persistence of women in the STEM disciplines and suggested "Women may be avoiding challenging careers in STEM not only because they erroneously believe that innate intelligence is needed for success in these fields but also because they erroneously believe that they belong to a group that is less likely to possess the qualities needed for success in these fields" (p. 126). If the women in this study chose to pursue biology as a major because they viewed the subject matter as devoid of math, the reformed course content was a source of discomfort and mismatched their expectations for learning in the subject.

The pattern that women perceived biology as separate from the more quantitative sciences is underpinned by their expectations for learning in biology that is potentially mitigated by the psychological-social phenomenon of stereotype threat. Smeding (2012) suggested a stereotype is "defined as the association of a group concept (e.g., men) with a given attribute concept (e.g., STEM)." "An important principle of this theory is that the association between two (initially) unlinked concepts (e.g., women and STEM) can be created and reinforced if these concepts share a common association with a third concept, the self" (p. 618). Since stereotype threat is situational, the inclusion of math, physics, and chemistry in the reformed biology course may have created an environment where negative stereotypes of women in science were unintentionally reinforced creating a dissonance between women's expectations for learning and actual learning in the course. In response, women potentially sought to express distaste for math and physics to maintain their self-concept (Steele, James, & Barnett, 2002). While women expressed a stance that the biology and physics/math content should remain in disciplinary silos, the quantitative results provide some dissonance to such a claim.

Men generally favored the inclusion of math, physics, and chemistry in the reformed course. Most men in the study shared a somewhat different view of the inclusion of quantitative subjects in the course to explain biological phenomena. Lee found the incorporation of thermodynamics laws "very helpful" to his learning in the course, and stated: "I'm not sure how to describe it, but I mean…I guess it made you actually think about the actual processes behind life instead of just say oh this is the second law of thermodynamics which must mean X. Instead it makes you think Ok now how can I actually meaningfully apply this to biology?" Lee's epistemic stance was sophisticated on several levels. His statement suggested that he not only viewed the inclusion of physics content in the course as meaningful to his learning but that physics and biology knowledge are constructed from consistent frameworks rather than "bits and pieces" (Muis, 2004, p. 320). He sought to "think" about his learning and the relationship of the reformed content to his knowledge construction. Instead of accepting that a concept meant "X" to be memorized, he sought to apply the information to his knowledge construction.

Michael also expressed a positive view of the inclusion of math in biology: He claimed that "I guess I just like math a lot." Michael connected his love of math to his chosen major, and stated, "It's interesting how stuff in nature applies to like math. Like my choice of majors, seemingly unrelated topics…biology and math". Here he made the connection between his love of math and its connection to the other disciplines. In this sense, Michael expressed an epistemologically sophisticated stance that math and nature are intertwined. While he perceived that math knowledge was connected to the world around him, he could not understand the relevance of biology. He complained, "I honestly completely hate bio. I really, really do." This finding was juxtaposed to the findings for women in the study who could find the relevance for biology knowledge, but not the for math/physics content.

He described later that biology has "just so much like extra stuff". He stated further, "Originally, I was going to be a biochem major because I thought biology was too easy. I guess I just like math a lot, so I feel that biological calculus isn't as good as real calculus." Wang and Degol (2017) suggested "that individuals are more likely to rate male-dominated fields as requiring innate intelligence or brilliance compared to fields with a larger proportion of women" (p.126). Michael's idea that biology is somehow easier than biochemistry demonstrated his field specific ability belief and may have led to his strong quantitative subject identification.

The male students' viewpoints that the inclusion of math, chemistry, and physics content in the course was valuable to their learning were consistent with research findings that concluded, "Boys report higher levels of self-efficacy than girls" for quantitative subjects (Schwery, Hulac, & Schweinle, 2016, p. 389). For the men in the course, the inclusion of quantitative content may have activated a male positive stereotype that created a favorable outcome for men (Shih, Pittinsky, & Ho, 2012) and reinforced the epistemological beliefs men may hold for learning in STEM.

Most of the men in this study appeared to manifest a positive connection with math that allowed them to accept the inclusion of the quantitative subjects in biology. Alex went as far as to characterize himself as a “math kind of guy”, clearly expressing his strong affinity for and identification with math. This high math identification potentially shaped the expectations men had for learning in biology and made them more receptive to the reformed course content.

The fact that men and women differed in their perception of the value of the inclusion of quantitative disciplinary content to their learning in the reformed course was a pervading pattern from the interview analysis, but there was an outlier man in the sample. Joseph expressed a dis-identification with math like the women discussed previously. He stated, “I don’t love math” and “would rather, I guess um, the biological subjects be mainly biology and not mainly um the chemistry involved, or the physics involved.” His resistance to the inclusion of chemistry and physics in the biology course appeared tied to his identification with math as a subject. Wang and Degol (2017) argued that there are certain field specific ability beliefs that are socio-culturally based and that a student’s “mindset” as it relates to a field can impact how a student identifies with a particular subject. In this case, Joseph’s statement reflected a fixed mindset – an epistemologically naïve viewpoint that knowledge is based on innate ability, rather than developed through hard work and active engagement with disciplinary content. If he did not believe that he had high math ability, his fixed mindset prevented him from identifying with quantitative subjects and influenced his viewpoint that biology knowledge should remain separate from the more quantitative disciplines of chemistry and physics. This outlier sub-theme was interesting in contrast to the other men in the study.

Level of epistemological sophistication influenced student response to the active learning environment for both men and women. The second key finding revealed two themes about how students experienced the active learning environment. These themes were not influenced by gender, but instead suggested that students with novice epistemologies for science learning found the active learning environment frustrating, while students with a more sophisticated epistemology appeared to have a positive experience with the learning environment. This finding demonstrated a potential disconnect between the student's expectation for what constitutes learning in a college-level biological sciences course and the pedagogy enacted in the learner-centered environment. The fact that students had mixed reactions to the active learning environment was consistent with the literature (Karabulut-Ilgu, Jaramillo Cherrez, & Jahren, 2017; Yadav et al., 2014). Karabulut-Ilgu et al. (2017) suggested that students may be resistant to the inclusion of active learning in a course because they have been inculcated throughout their educational career by traditional pedagogy. This indoctrination creates a certain belief of what it means to learn in a biological sciences classroom and may make the shift to a new approach uncomfortable for students.

Novice epistemologies shaped negative views of the learning environment.

Students who expressed more novice beliefs about what constitutes learning in a biological sciences classroom found the course frustrating and couldn't understand why the faculty members did not want them to memorize information. Katy explicitly expressed, “We’re not supposed to memorize things”. She suggested that she was “just making it through alive” and her peers in the course agreed and “don’t understand what’s the point of why we’re taking this class.” The objective of developing a deeper understanding of biological concepts was mismatched with her belief that “biologists tend to memorize things more than apply things.”

Similarly, a male student, Lee, expressed his confusion about the goal of the course. He asserted: “I will say that the teaching style of my professors is very unique. I mean I have never had a professor that has had such disdain for just plain memorization.” Allison, a student with a positive view of the course acknowledged that “people would get annoyed” with the pedagogy and suggested that students who were resistant to the approach were less sophisticated in their learning. She shared, “I feel like those are the people who are memorizers.” These students demonstrated unsophisticated epistemic beliefs that the structure of knowledge in biology consists of facts to be memorized rather than broader principles to be applied.

Kirschner (2009) suggested that “Novices spend a great deal of effort attempting to remember and process individual elements” (p. 148). In this course students were asked to work collaboratively and solve complex problems to gain deeper meaning and conceptual understanding. For students with a novice approach to learning, their expectation to be a passive recipient of content was juxtaposed with the classroom environment. This potentially led to their expressed dissatisfaction with the reformed pedagogy.

Ellen proposed that she understood the value of the pedagogy, but the approach may not be well-connected to her performance in the course. In referring to the course faculty, she blamed herself, “I guess that’s all on me. Because as far as I’m concerned they’re doing a pretty good job and I’m just studying the wrong way.” Ellen asserted that testing “is just recalling facts” which indicated that while she appreciated the instructor’s pedagogical approach, her own approach to studying did not reflect a more expert stance. Michael also demonstrated some resistance to the enacted pedagogy in the reformed course. For example, he stated:

> Well...It's good to talk to people. You know I'm not very social so that's always good. And then um...It's good to like review what you learn in class because I have a tendency not to do that. So we went over the first and second laws of thermodynamics. And when you're in a group I personally feel that like I'm pressured to show that I'm not just like lazy and I know something so I feel like I have to speak in a group and that kind of helps reinforce things because I can tell I'm kind of passive generally so I feel I have to prove myself when I'm in a group.

Michael’s comments suggested that the group dynamic may have increased his stress, an unintended consequence of the intervention. If Michael was operating from an unsophisticated epistemological belief that science is a solitary endeavor, his resistance to the active learning environment would make sense. Arner-Welsh (2010) suggested that “There may be a conflict between the needs and values of science itself and the needs and procedures of the classroom setting for educating science students” (p. 101).

These findings demonstrated that the novice beliefs that men and women held about what counts as learning in biology may have impacted their perception of the active learning environment. While incorporation of active learning strategies has been recommended by policy makers as an approach to improving student learning outcomes, student resistance to this new environment is a potential challenge faced by faculty members.

Sophisticated epistemologies shaped positive views of the learning environment. Students with a positive view of the learning environment described the GAEs as "challenging" and found themselves "thinking in new ways and making new connections" as a result. A female student, Leah, enjoyed the activities in the course and felt that they improved her learning and created an environment that was conducive to knowledge construction. She acknowledged that the activities are "all part of making you learn the material, not just memorize it," and stated:

> So the class itself seems like it seems less stressful...like than maybe like previous classes just because they're really emphasizing like team work and working together with your groups so you don't feel like you're doing it on your own...but the same time it's like it's something new for all of us.

Leah's sense that collaborative group work created a "less stressful" environment is consistent with the literature that suggests the incorporation of active learning into STEM courses may decrease the competitive STEM environment that favors men's ways of knowing over women's ways of knowing (Sinnes & Loken, 2012).

Men also shared this positive view of their learning in the course. They described the GAEs as "very interesting" and suggested that the activities "made you actually think about the actual processes behind life." Jason suggested that the GAEs encouraged active knowledge construction over memorization: "If you just memorize all the little structures and facts about organisms, and don't understand where they come from and why things change, I think that undermines the point of learning about biology." It is possible that the men and women who found value in the learning environment had more sophisticated beliefs about what it means to learn in biology and this epistemic belief shaped their receptiveness to the pedagogy. Kirschner (2009) suggested that students with a more expert stance "have a great deal of accessible content knowledge organized to reflect deep understanding of the subject matter." This more expert stance may be better aligned with the reformed course pedagogy than the novice stance revealed by students who communicated frustration with the course.

Summary of Qualitative Findings

The qualitative thematic analysis of student interview transcripts revealed two key findings. The first finding suggested that gender played a role in how men and women perceived the inclusion of quantitative content in the course. In this study, women demonstrated resistance to the inclusion of the quantitative content, while men appreciated its inclusion in the course. I proposed that the prevailing stereotype that men are better at math than women may have created this unintentional outcome in the reformed course. Men who had low-math identification may have held to a fixed belief that math ability is innate and poor math ability would prohibit success in the course. Men with high math identification were receptive to the inclusion of math in the reformed course. The second key finding revealed that a student's level of epistemological sophistication influenced their receptiveness to the inclusion of active learning strategies in the reformed course. Students with a more sophisticated epistemological stance that knowledge development is a process of active construction seemed to appreciate the inclusion of active learning in the course, while students who viewed knowledge as something to be passed from teacher to student were not receptive to its inclusion.

Integration of Results and Findings

While the quantitative and qualitative analyses were conducted separately, there were areas where the results and findings converged and expanded the interpretation of two data streams. Table 16 depicts the relationship between the quantitative results and the qualitative findings.

Facts versus Principles

The results of the quantitative analysis found no relationship between men and women at pre-test or post-test. The qualitative findings supported this outcome as both men and women expressed sophisticated views regarding the structure of knowledge in the biological sciences. While the quantitative results demonstrated significant positive shifts for both men and women in this cluster, the qualitative findings suggested that naïve epistemologies that biological knowledge consists of isolated facts to be memorized existed and may cause a disconnect between the pedagogy and the students' expectations for learning in the reformed classroom. Despite some resistance, the reformed, learner-centered curriculum was successful at creating more epistemologically sophisticated students. By the end of the semester, the students had a stronger understanding that biology is not a set of facts to be memorized. Rather, biology consists of broad principles.

Table 16 Joint Display of Quantitative Outcomes and Qualitative Findings

MBEX I Cluster	Outcomes	Qualitative Findings
Facts v. Principles	No gender differences at pre- or post-test Significant positive shift for men and women	Level of epistemological sophistication influenced perception of the structure of biology knowledge
Isolated v. Connected	No gender differences at pre- or post-test	Level of epistemological sophistication influenced perception of the purpose of biology education Positive view of biology for both men and women
Authority v. Independence	No gender differences at pre-test Significant gender difference at post-test Significant positive shift for men and women	Level of epistemological sophistication influenced student perception of learning environment
Silo-maintenance v. Interdisciplinary	No gender differences at pre- or post-test	Level of epistemological sophistication influenced student perception Gender influenced the perception of inclusion of quantitative content in the reformed course Low math identification influenced perception of inclusion of quantitative content for men

Isolated versus Connected

The quantitative analysis indicated there was no significant gender relationship at pre-test or post-test in this cluster, but that both men and women declined slightly in their understanding that biology content is connected to the real world. Although this trend was statistically non-significant ($p < .05$), it is possible that the inclusion of quantitative content in the reformed, learner-centered content in the course could have influenced the student's beliefs that biology is tangible. The qualitative analysis, nonetheless, suggested that both men and women expressed positive viewpoints about the link between biology and the real world. They even shared their view that they chose biology as a major because of its connection to the real world.

Authority versus Independence

The quantitative analysis indicated that there was no significant difference between men and women at pre-test, but there were significant gender differences at post-test in this cluster, with women responding more favorably to the active learning pedagogy than men. However, the repeated measure ANOVA discovered no statistically significant interaction of time by gender. This is consistent with the qualitative findings that demonstrated both men and women acknowledged that the reformed course made them think more deeply about what they were learning in the course, particularly the students with more sophisticated stances. The qualitative findings suggested that there may have been some resistance to the pedagogy for both men and women, particularly by students with less sophisticated epistemologies.

Silo-maintenance versus Interdisciplinary Perspective

There were no differences between men and women at pre-test or post-test in this cluster. However, there were near significant positive shifts for both men and women after one semester of instruction in the reformed course ($p < .06$). Nonetheless, the qualitative findings suggested that women in the study resisted the inclusion of quantitative disciplinary content in the reformed learner-centered organismal biology course, while most men interviewed expressed positive views about the inclusion of this content. The distaste for math expressed by the women in the course may make the inclusion of this content more challenging for women to embrace.

Summary

Chapter 4 summarized the qualitative findings and quantitative outcomes of the mixed methods secondary data analysis. Chapter 5 provides a discussion of the conclusions of the study in relationship to the literature on gender, student epistemology, and learning in the sciences and suggests deeper meaning of the results and findings.

Chapter 5: Conclusions

Summary of Study Problem and Methods

Biology is a discipline that is becoming increasingly interdisciplinary, drawing more strongly on other more quantitative STEM disciplines. Evidence demonstrates that women remain underrepresented in most STEM disciplines and that inclusion of active learning in STEM classrooms may create a more gender neutral classroom environment than traditional large lecture pedagogy. Reform advocates suggest that faculty need to transform biology classrooms by including quantitative content and active learning strategies (AAAS, 2015; NRC, 2009) to meet the demands of the future workforce. STEM curricular and pedagogical change comes with certain challenges that faculty must face to produce successful outcomes (Karabulut-Ilgu et al., 2017). The literature suggests that students bring certain beliefs about subject matter and what constitutes learning in a biology course to their classroom experience. These epistemologies may impact how students experience a reformed active learning course (Hall, 2013).

There is a robust literature base describing how epistemologies shape student experiences and learning in the STEM classroom. To date, much of the work conducted in this realm has been in the physical sciences, with very few studies examining how student epistemologies shape learning in biology courses. Given that gender equity in STEM remains an issue, exploring the relationships between gender, pedagogy, and epistemologies presents an opportunity for researchers and reformers to further understand how active learning and the inclusion of physical sciences and math is experienced by students in the reformed biology classroom. This study expanded the previous work in this area and provided an exploration of how men and women experience learning in a reformed, learner-centered organismal biology course.

The purpose of this study was to explore the dimensions of gender and student epistemologies as they were manifested in the course. The project was conducted as a mixed methods secondary data analysis of data collected by Hall (2013). The study expanded the scope of Hall's original study to include gender. The current study used t-tests and RM-ANOVA analysis of pre-test/post-test MBEX I data to determine if gender played a role in student epistemologies in four dimensions (*Facts versus Principles, Authority versus Independence, Isolated versus Connected, and Silo-maintenance versus Interdisciplinary Perspectives*). Thematic qualitative analysis (Braun & Clarke, 2006) of eight (four women/four men) hour-long participant interviews expanded the quantitative results to provide deeper insight into how gender and epistemologies may have influenced student experiences in the learner-centered pedagogical context. The goal of the study was not to interpret the quantitative results in light of the qualitative findings, but rather to expand our understanding of how student epistemologies and expectations for learning in biology may interact with gender in the reformed course.

In the next section, I provide a summary of the results and findings from the quantitative and qualitative analyses.

Summary of Results and Findings

The t-test results demonstrated that there was no significant difference between men and women in any of the four dimensions of the MBEX I at pre-test or post-test, with the exception of the *Authority versus Independence* cluster at post-test. There were significant differences between men and women at post-test in this cluster. The RM-ANOVA results indicated that while there were no significant differences in the pre-test/ post-test epistemological changes between men and women, the reformed course produced significant positive epistemological shifts for both men *and* women on the overall instrument and in the *Facts versus Principles* and *Authority versus Independence* clusters. There were also near significant positive epistemological changes for both men and women in the *Silo-maintenance versus Interdisciplinary Perspectives* cluster. The fact that there were not significant differences at pre-test and post-test in the *Isolated versus Connected* cluster was consistent with Hall (2013), who also found a decline in epistemological sophistication in this cluster, though primarily associated with students in traditionally taught classrooms.

Facts versus Principles Cluster

One aim of a reformed organismal biology course is to produce students who can think critically about biological principles and actively construct knowledge when they are developing meaning and understanding. Given that the faculty intentionally developed the course to expose students to the idea that biological knowledge consists of principles to be applied to complex problems, I expected to see maturation of epistemologies in this cluster. The fact that both men and women experienced significant positive shifts in this category suggested that the reformed course was successful in meeting this objective in one semester.

Authority versus Independence Cluster

The fact that both women and men experienced significant positive shifts in the *Authority versus Independence* cluster was consistent with the work of Hall (2013). She found an increase in favorable responses and a decline in unfavorable responses in both the honors and non-honors section after one semester of instruction in these reformed courses. The results suggest that the reformed pedagogy was successful at producing a student with a more constructivist view of knowledge development.

However, there were mixed results in the qualitative analysis that suggested students with less sophisticated expectations for learning in the course were resistant to the pedagogy. They may have found the approach unfamiliar and uncomfortable, specifically suggesting that the professors had a “disdain for just plain memorization”. If the students entered the reformed classroom with the naïve epistemic stance, that success in the course is equivalent to memorizing facts directly from the book and regurgitating them on a multiple-choice exam, this expectation may have negatively interacted with the faculty’s expected outcome for the course. Despite some expressed resistance to the pedagogy, the course was still able to produce more sophisticated students by the end of the semester. This suggests that the GAE were effective tools in producing positive epistemological change.

Isolated versus Connected Cluster

The results for the Isolated versus Connected cluster were consistent with Hall's (2013) study outcomes. She concluded that the reformed learner-centered course was not effective in shifting the student's views that biology is relevant to the real world and can be applied broadly.

The qualitative findings of this study suggested the opposite. The reformed course was able to help students view biology's application to the real world. Both men and women reported that biology was "tangible" and "real". In fact, the view that biology had real-world applicability was the reason many men and women cited for choosing biology as a major over the other STEM disciplines. Perhaps, the incorporation of quantitative content was disconnected to the students underlying beliefs about biology and led to the failure to achieve statistically significant improvements in the epistemological sophistication in this cluster.

Silo-maintenance versus Interdisciplinary Perspectives Cluster

There were positive shifts for men and women in the *Silo-maintenance versus Interdisciplinary Perspectives* cluster that were nearly significant at $p < .05$. With a slightly higher criterion, the results in this category would have fallen in the significant range. The purposeful inclusion of interdisciplinary content in the course encouraged students to become less resistant to the idea that biological sciences knowledge is connected to other disciplines. While both men and women increased their scores in this cluster, the qualitative findings suggested that women held expectations that biology should be devoid of math and/or "letters and numbers" and expressed strong views that the disciplines should remain in silos.

The women's sense of scientific disciplinary identity in the context of the reformed course could have been shaped by pervasive gender stereotypes that women are less competent at math than men. The social construction of this math distaste may have been enacted in the classroom and could have made women resistant to the reformed content. While men generally found the inclusion of math and physics content "helpful", certain naïve epistemologies expressed by an outlier man may have impacted his reception to the inclusion of this content in the course.

Despite the underlying personal preference for math remaining separate from biology, the course was still successful at shifting both men and women to more sophisticated thinking. The direction of the results was consistent with the work of Hall (2013). She found the most significant positive shifts in this cluster. The discrepancy between the non-significant outcome of this study and the work of Hall (2013) may be explained by methodological difference. Hall's analysis assumed that the variables in the MBEX I dimensions were not orthogonal, so Hall used Bayesian analysis to examine shifts between favorable/neutral/unfavorable categories. I made no assumption about the relationship between the epistemological dimensions and chose to explore the potential changes in epistemological dimensions through an analysis of means.

Conclusions

The results and findings summarized previously produced three main conclusions about the relationship between gender, student epistemologies, and the reformed organismal biology course:

1- The reformed learner-centered course helped both women and men see biology as principles-based and biology knowledge as constructed.

2- Gender and math preference may affect the receptivity of inclusion of interdisciplinary content in reformed learner-centered courses.

3- Inclusion of interdisciplinary content in reformed courses can impact how biology majors view the relationship of biology to the real world.

Conclusion 1

The reformed learner-centered course helped both women and men see biology as principles-based and biology knowledge as constructed. To think like a biologist, reform agents have suggested that students must view biology knowledge as being principles-based rather than facts-based, and be able to actively construct knowledge. The reformed pedagogy in the course was successful at achieving these two objectives for both men and women, which is a reassuring finding for reform-minded educators. While there were students who expressed a viewpoint that biological sciences knowledge is concrete and relayed to a student from an authority (e.g. faculty, textbook), they still became more constructivist in their thinking about their learning by the end of one semester of instruction in the reformed classroom.

For women, the active learning environment and GAE activities were helpful in shifting their beliefs to a more epistemological stance that knowledge is constructed. Belenky et al. (1986) described unsophisticated stances that women hold in relation to the nature of knowledge and knowing. In this study, women shifted from an exhibition of silence (a lack of power in knowledge development) and received knowledge (knowledge from authorities) to a more participatory and constructivist stance, a more sophisticated epistemological stance according to the literature.

For the men, their beliefs about knowledge as being certain could have created a resistance to epistemological change, but this resistance was overcome by the end of the course. Hofer (2000) concluded that men more than women held beliefs about knowledge being unchanging and found value in the expertise of authority figures. The men's strong respect of the expertise of an authority figure may have made them less likely than the women to positively shift in their thinking; nonetheless, the learner-centered curriculum was successful in facilitating the shift in men.

Kessels (2013) suggested that women hold certain "psychological obstacles" (p. 259) that may affect epistemic stances, but found that both men and women can have different epistemic stances that influence the perpetuation of unsophisticated views. In this instance, the active learning pedagogy allowed women and men to overcome naïve epistemic beliefs and move beyond silent acceptance that knowledge comes from outside themselves. The pedagogy allowed women and men to interact and think deeply about the content moving both beyond their belief of knowledge as received.

As the GAEs are utilized in the group dynamic, it may be interesting to explore how the students' perceptions of sharing power in the group activity is enacted and further explore the effectiveness at removing the barrier to developing epistemological sophistication in the reformed course. Although I discovered no gender differences in epistemological change, a closer look at group dynamics may shed additional light on how GAEs might have differential influences on women and men in STEM-related learning environments.

Educational reform is important to meet the future demands of the scientific workplace. The outcomes of this study indicated that there are interacting epistemological beliefs about what counts as knowledge and learning in a biological sciences classroom that influenced how students responded to the reformed course content and pedagogy, but that epistemological maturation is still a positive outcome of reformed, active learning classrooms.

Conclusion 2

Gender and math preference may affect the receptivity of inclusion of interdisciplinary content in reformed learner-centered courses. The qualitative findings suggested that some men and most women were resistant to the inclusion of quantitative content in the course. Despite this resistance to math inclusion, the quantitative results indicated that both men and women became more epistemologically sophisticated by the end of the one semester course, particularly regarding *Facts versus Principles* and *Authority versus Independence*. What could explain this result? For the women in the study it is possible that the stereotyped differences between women and men, wherein men are viewed as more capable at math than women, influenced the women’s expressed resistance to inclusion of the quantitative content. Research indicated that gender stereotypes around math ability begin early in the educational pipeline and that these stereotypes persist into college (Wang & Degol, 2017). If the women in this study were influenced by persistent negative beliefs about their math ability, it would make sense that they would find the use of equations to inform their understanding of biology irrelevant. Despite this underlying distaste for math expressed by the women, the course was still able to shift their epistemologies to a more positive stance.

While most men expressed more sophisticated views of the inclusion of math in the reformed course and were able to activate the resource for mathematical problem-solving in the context of biology, other men adhered to a fixed mindset about their math ability and its role in the course. Hammer and Elby (2003) argued that students have a set of epistemological resources that they can enact in different contexts. The men in this study may have held positive beliefs about math ability and that belief translated to activation of a sophisticated interdisciplinary view in the reformed course. Women who expressed a distaste for math inclusion were still able to see the relationship between biology and other scientific disciplines by the end of the course. Their expressed resistance to math inclusion appeared to not influence their epistemological maturation. This is an implication for the reform of biology education. It may mean that educators need to identify and attend to areas where students are resistant to inclusion of quantitative content in order to impact epistemological change. The instructor in this course used GAE to intentionally introduce content from other disciplines in order to effectively revamp the biological sciences curriculum to meet the needs of the 21st century biologist. This approach was successful at shifting men and women to a more positive epistemological stance in two clusters, but the women's expressed distaste for math content may have influenced the outcome in the other clusters.

Reform-minded educators should consider possible barriers to men and women engaging positively with reformed content in their courses to ensure both men and women continue to have positive epistemological shifts. This may indicate that instructors need to acknowledge the strong sense of math dis-identification amongst women and develop strategies to remove this potential barrier to epistemological change.

Conclusion 3

Inclusion of interdisciplinary content in reformed courses can impact how biology majors view the relationship of biology to the real world. All students in this study were biological sciences majors suggesting that they were drawn to the major because they thought the major was an appropriate path to achieving their long-term goals. It is possible that the inclusion of quantitative content in the reformed course negatively influenced these biology majors view that the course was related to the real world. In the interviews, some students described biology as being “tangible” and suggested that they chose to be biology majors because there was “no math in it”. Cotner, Thompson, and Wright (2017) discovered biology majors found biology content relevant to their personal lives and long-term goals, but Perkins, Adams, and Wieman (2007) found that biology majors do not believe chemistry is connected to the real world. Mason and Bertram (2016) discovered that biology majors favor a framework-orientation, while physical sciences majors favor a performance-based orientation. They concluded that when engaging in problem-solving activities, “diversity of majors appears to be linked to an epistemic disparity that presents a challenge to problem-solving framework pedagogies" (p. 247). This epistemic disparity could have played out in the reformed, learner-centered course resulting in the slight, though not statistically significant, decline in epistemological sophistication in the *Isolated versus Connected* cluster.

This outcome may be important as we seek to reform biological sciences courses to include interdisciplinary content and keep the STEM pipeline strong. Career connectedness of student future career goals to major is an important indicator of persistence in STEM (Shell, Soh, Flanigan, & Peteranetz, 2016). Reform-minded educators may need to develop strategies to explicitly connect biology courses and reformed content to student long term goals to ensure persistence in the biological sciences.

Limitations of Study

The following limitations are related to this study:

1- This study explored how student epistemology and gender influenced student responses to a reformed learner-centered organismal biology course. The course was one of three undergraduate organismal biology courses taught at a large research university. This specific course construct might limit the generalizability of the findings to organismal biology at similar institutions and may not inform courses taught at smaller institutions, in other biological science courses or pedagogical contexts

2- I evaluated epistemological change by analyzing secondary data drawn from a study that utilized the MBEX I instrument (Hall, 2013), but other tools are available that measure epistemological change. There may be more sensitive instruments available to provide a more nuanced view of the relationship between gender epistemology in the reformed course.

3- I compiled the results of honors and non-honors sections into one data set for analysis. This may have influenced some of the outcomes, particularly for the qualitative analyses, which only included interviews with honors students.

4- Given the secondary nature of this study, I relied on the good data practices of the original research team. I drew interview data from the original study and was not able to interact with the students who were interviewed to verify or expand the thematic analysis. If I had conducted the interviews myself, I would have been able to probe students with questions specifically designed to illicit their perceptions on the role gender may have played in their experiences in the reformed course. I would also have been able to re-interview students after initial data familiarization and coding to expand the qualitative analysis further.

Recommendations for Future Research

By exploring the potential relationships between gender and student epistemologies in a reformed organismal biology course, this study provided some insight into how students may embrace or resist reformed content and pedagogy in an undergraduate organismal biology course.

To date, much of the research related to epistemological beliefs has been conducted in physics. I suggest that researchers in all STEM disciplines continue to explore the intersection between gender, epistemologies, and pedagogical contexts as we seek to improve student learning outcomes and the pipeline of women in science. One goal of science education is to create environments that support learning for both men and women. I would recommend that future researchers attend to the role gender may play in the experience of women in reformed courses to ensure that both men and women find benefit in the learning environment. This type of analysis could also be important from the lens of how various racial and ethnic groups of students experience the reformed learner-centered environment.

Another potential area for future research is to examine the roles math self-efficacy and stereotype threat may play in women's experience of reformed biology courses that include quantitative content. It is also possible that there were certain power struggles enacted within the group dynamic of the GAEs that could have influenced the women's epistemological sophistication. While an investigation of such group interactions was beyond the scope of this study, there may be a future research opportunity to explore how gender functions in group interactions in these exercises that may influence outcomes.

Finally, as a secondary data analysis, I was unable to explore gender as a social construction rather than a biological one. There may be nuances that were missed by not having this level of analysis in the current work, and it could be valuable to explore how the social construction of gender influences student receptivity to reformed courses.

Appendices

Appendix A: Unpublished Analysis

Exploring Epistemologies by Gender in a Reformed-content, Traditional-pedagogy Organismal Biology Course

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Abstract

This paper explores the relationship between gender and student epistemologies in a reformed-content, traditional pedagogy organismal biology course. Student epistemologies were measured using the Maryland Biology Expectations Survey (MBEX I) that was provided to students at pre-test (beginning of the semester) and post-test (end of the semester) at a large, east coast university. The MBEX I instrument captured information about student epistemologies for learning in biology. Independent t-tests were used to determine if there were differences between men and women's epistemologies at pre-test and post-test. Repeated Measures Analysis of Variance was utilized to determine if there were significant shifts in student epistemologies after one semester of instruction in the course. Both men and women demonstrated significant positive shifts in the *Facts versus Principles* (p =.03) and *Isolated versus Connected* (p =.00) clusters after one semester of instruction in the reformed-content, traditional-pedagogy course. The near significant significant (p=.06) decline in the *Silo maintenance versus Interdisciplinary Perspectives* cluster for both men and women suggested a resistance to the inclusion

of math and chemistry in the biological sciences course content for both men and women.

Introduction

Advances in the life sciences will create solutions to complex societal problems, such as limited food supply, lack of environmental resiliency, energy inefficiency, and threats to individual health and wellness. New fields emerging within the discipline are increasingly interdisciplinary, quantitative, and draw on other science, technology, engineering, and math (STEM) disciplines (National Research Council [NRC], 2009). The biologist of the future will require strong computational skills, the ability to integrate information from multiple disciplinary perspectives, and skill in effectively communicating and collaborating on multi-disciplinary teams (American Association for the Advancement of Science [AAAS], 2011, 2015). The NRC (2009) described this individual as "not a scientist who knows a little bit about a lot of disciplines, but a scientist with deep knowledge in one discipline and basic fluency in several" (p. 20). These reform minded agencies suggested that institutions think about the inclusion of interdisciplinary content as a vehicle to produce the type of scientist needed in the future.

When students enter the biological sciences classroom, they bring prior conceptual knowledge (Trujillo & Tanner, 2014) and certain epistemologies, as well as beliefs about the nature of knowledge and knowing (Hofer, 2000, 2004), that may interact with their expectations of the classroom environment (Hall, 2013), and influence learning outcomes (Lising & Elby, 2005; Ding & Mollohan, 2015; Mollohan, 2015; Schommer-Aikins & Duell, 2013). The goal of undergraduate

STEM education is to produce students with a deeper understanding of scientific principles whose beliefs about the nature of knowledge and knowing are more like experts in the discipline. Science experts understand that the nature of scientific knowledge is not fixed; rather, it is unsettled with opportunities for theoretical evolution as new findings emerge. When learning in the sciences, experts know that scientific knowledge is not a collection of isolated facts to be memorized with little or no connection to the real world or other scientific disciplines.

Studies have demonstrated that the traditional lecture-based approach to teaching in the sciences negatively impacts student epistemologies, resulting in students with less sophisticated views of science and science learning (Hall, 2013; Hammer & Elby, 2003; Hoskins, Lopatto, & Stevens, 2011; Redish, Saul, & Steinberg, 1998). Dai and Cromley (2014) concluded further that the negative shift of student epistemologies that can occur in traditional lecture-based classrooms may influence the STEM pipeline. Feminist theorists suggest further that this pedagogical approach creates a learning environment that fails to foster a sense of belonging for women (Dasgupta & Stout, 2014) and impacts their self-concept for learning in the sciences (Seymour & Hewitt, 1997).

To date, close to half of all current STEM majors will not persist to graduation in their chosen field (United States Department of Education, National Center for Educational Statistics [NCES], 2017). Of those students who do graduate in a STEM discipline less than thirty percent are women, representing “untapped human capital that, if leveraged, could enhance the science technology engineering and math (STEM) workforce” (Dasgupta & Stout, 2014, p. 21). While the gender gap in biology is smaller than in other STEM disciplines, there remains a void of women in the biological sciences at the higher levels (Hill, Corbett, & St. Rose, 2010) that suggests an ongoing lack of gender parity in the discipline. According to Nielsen et al. (2017), “When it comes to science collaborations, there’s ample data to suggest that gender diversity pays a substantial research and productivity dividend” (p. 1740). To create sustainable solutions to the problems facing the future global marketplace, women have the potential to make a significant impact.

As faculty reform college-level biology courses in response to policy maker recommendations, it remains important to understand better how women and men experience these changes and explore how their epistemologies for learning in the discipline may shape that experience. Muis and Gierus (2013) contended that “epistemological thinking matters” (p. 408) to curriculum reform initiatives. This study explored the dimensions of gender and student epistemology in the experiences of women and men in a reformed-content, traditional-pedagogy, large lecture organismal biology course taught at a large, east coast institution. The instructors of this large lecture course reformed the content of the course to incorporate the content of math, physics, and chemistry. By purposefully including quantitative content and theories in the reformed-content, traditional-pedagogy course, the faculty members attempted to develop the sophisticated thinking beneficial to the 21st century biologist.

Statement of Problem

Critics of undergraduate biology curricula and pedagogy contended that the popular teacher-centered, large lecture-based environment is not sufficient to produce a diverse workforce with the type of critical thinking and epistemological sophistication needed to lead scientific development in the 21st century (Hill et al., 2010). Evidence suggested that the traditional lecture-based approach emphasized passive learning and rote memorization over critical thinking (Knight & Wood, 2005), created a culture of competition that contributed to women feeling unworthy of producing successful outcomes in STEM courses (Schubert & Bowker, 2017), and impacted the ongoing gender disparity in the STEM pipeline (Wilson & Kittleson, 2013). Additionally, students failed to comprehend core biological science concepts after instruction (Agorram et al., 2010; Marbach-Ad & Stavy, 2000; Smith & Knight, 2012), had difficulty integrating complex concepts with their existing science knowledge (Newman, Catavero, & Wright, 2012), and became less sophisticated in their epistemologies (Hall, 2013) when taught in this format.

In transforming biology courses to meet the needs of the future global marketplace, researchers encouraged faculty to attend not only to producing enhanced cognitive outcomes, but also to influencing student epistemologies positively (AAAS, 2011; Hall, 2013; Hammer, Elby, Scherr, & Redish, 2005). Hill et al. (2010) suggested that such a transformation might promote the retention of diverse STEM students in the profession. This study adds to the epistemological research base in biology education, and provided a more nuanced understanding of how women and men experience a reformed, traditional large lecture organismal biology course.

Theoretical Perspectives on Science Learning and Epistemology

According to Kelly, McDonald, and Wickman (2012), “Epistemology is a branch of philosophy that investigates the origins, scope, nature, and limitations of knowledge" (p. 281). To frame their work, they described three epistemological perspectives that provide a foundation and lens for understanding learning in the scientific disciplines. These three lenses are referred to as the disciplinary, personal ways of knowing, and social practices perspectives. While these epistemological perspectives are presented here as distinct frameworks, there are common tenets amongst the three. In this study, I acknowledge that all three perspectives may influence how students learn in the reformed-content, traditional-pedagogy classroom.

Disciplinary Perspective

The disciplinary perspective was built on the work of historians and philosophers of science (Dewey & Hickman, 2007; Kuhn, 1977). Proponents of the disciplinary perspective maintained that there are characteristics of professional scientists and practices conducted by these scientists that are different than those enacted by other professionals. The disciplinary perspective of knowing, values the relationship between the nature of science (NOS) and the student's view of the NOS. Student learning from this perspective is the "understanding that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (influenced by scientists' background and experiences), partly the product of human imagination and creativity (involves invention of explanations), socially and culturally embedded, the distinctions between observations and inferences (scientific knowledge is partly a function of each), and the relationships between scientific theories and laws" (Khishfe & Lederman, 2007, p. 941).

Following this line of reasoning, the job of the science educator is to teach students to understand the norms and engage in practices that are the hallmark of the scientific profession (Russ, 2014). This sets up a continuum of learning where students are viewed as “novices” and professional scientists are viewed as “experts”. Russ (2014) suggested there are potential risks in framing science learning from such a “unitary, singular” construct. She argued that students need to negotiate scientific content and construct knowledge within a context of his/her past experiences and knowledge base at a moment in time. To this end, she acknowledged that individuals have a personal way of knowing that interacts with epistemology of science as he/she constructs understanding.

Personal Ways of Knowing

The personal ways of knowing perspective emerged from William Perry’s (1970) work on college student learning. Perry described student learning as being inherently developmental and occurring on a continuum. During the learning process, students move from the naïve stance that knowledge is concrete, and teachers are the authority, delivering facts to students to be memorized, to the more sophisticated understanding that learning requires integration and reflection. Researchers who view science learning from this perspective focused on “ideas individuals hold about knowledge and knowing” (p. 353).

Hammer et al. (2005) contended this developmental continuum reflects an idea of “knowledge as stuff” (p. 112). The knowledge in this context is viewed as being correct or incorrect with expert views being stable constructions occurring int the same way in every domain. However, Elby and Hammer (2001) suggested that epistemologies are more contextual, finer grained resources that have a social base.

Social Practices

The social practices perspective “considers the social practices that determine what counts as knowledge in local, contingent contexts” (Kelly et al., 2012, p. 282). Theorists aligning with the third perspective posited that students have “multiple epistemological resources for understanding the source of knowledge and these different resources get activated in different contexts” (Hammer et al., 2005, p. 97). The accurate activation of these resources in new combinations plays a role in learning and teaching students to “become deliberative and reflective about their own learning process” (Hammer et al., 2005, p. 115). Dufresne, Mestre, Thaden-Koch, Grace, and Leonard (2005) proposed, “Learning can be characterized as a change in the state of a brain that would produce a different pattern of activation/application of knowledge in future responses to a particular context” (p. 190). To maximize student learning, it is important for faculty members to provide reformed content, but also to examine how a student’s epistemology shapes his/her learning in undergraduate biological sciences courses.

Lising and Elby (2005) reported that a “student’s personal epistemological stance — her ideas about knowledge and learning — can have a direct, causal influence on learning” (p. 372). Hammer et al. (2005) found that “transfer of epistemology led to further transfer at the level of conceptual understanding” (p. 111) in an undergraduate physics course. In this study, students with a less sophisticated epistemology for learning in physics struggled with conceptual understanding when faculty attended to the student epistemologies, in addition to conceptual understanding. In the first study of its kind in the biological sciences, Hall (2013) examined a traditional organismal biology course and explored how pedagogy affected shifts in student epistemologies. Her results indicated that transforming the content of the course to include connected, interdisciplinary approaches alone was not sufficient to produce epistemological shifts to a more sophisticated view. In fact, students in these traditional courses who were taught using the traditional, teacher-centered lecture approach had a less sophisticated view of biology than they had at the beginning of the semester after one semester of instruction. This negative shift of epistemologies occurred despite alignment of the curriculum to “New Biology” needs. On the other hand, students who experienced a traditional biology course taught with the inclusion of learner-centered, active learning activities had more sophisticated views of biology at the end of one semester of instruction, suggesting that learner-centered pedagogy produced epistemologically more sophisticated biology students (Hall, 2013).

Furthering the personal ways of knowing perspective, feminist theorists suggested that knowledge construction in the sciences is a personal process that occurs within a social context (Arner-Welsh, 2010), and the very nature of science is inherently authoritative and masculine. Women develop in a complex social system with experiences viewed through a gendered lens. Their experiences influence how women construct and make meaning of knowledge. Women learning in biology are often navigating their own knowledge construction in the context of the social norms around them. Arner-Welsh (2010) suggested, “If girls are drawing on specific epistemologies that are interfering with the performance of or interest in science, then studying the concrete ways in which girls are utilizing these epistemologies will enrich our understanding" (Arner-Welsh, 2010, p. 3).

The relationship between science knowledge, epistemology, and gender is inherently complex. It was not the goal of this researcher to narrow this study to causal relationships between gender and outcomes or retention of women in the sciences; rather, it was to explore how epistemology and gender manifested in a learner-centered science classroom so that we can better inform future efforts of pedagogical change. Drawing on the work of Russ (2014), the focus here was on the norms, values, interactions, and context the individual learner brought to the construction of knowledge in the science classroom.

Kelly et al. (2012) suggested that researchers interested in epistemology and science learning "draw from and are informed across perspectives. These perspectives may be mutually supported, or in some cases offer divergent directions for research" (p. 288). In this study, I acknowledged that women construct knowledge in relation to their personal experiences in a social setting, and that this learning takes place within the context of a scientific discipline. As such, the theoretical framework for this study was informed by all three epistemological perspectives presented previously.

Research Design and Methods

I conducted a secondary data analysis of three semesters of data collected by Hall (2013). Hall's work employed a mixed methods approach with pre-test/post-test design (Trochim & Donnelly, 2008) to compare the shifts in student epistemologies in a reformed organismal biology course taught via a traditional lecture approach.

Hall measured epistemologies quantitatively using the MBEX I instrument, and she explored students' understandings of epistemologies and experiences in the course via semi-structured student interviews, classroom observations, and focus groups.

Hall concluded that student epistemologies became less sophisticated after one semester of instruction in the traditional classroom environment but became more sophisticated after one semester of instruction in the learner-centered environment. Her qualitative interviews substantiated these results. While Hall's work exposed the negative impact of traditional lecture pedagogy on student epistemology, she did not include an analysis of whether decline of epistemologies in the reformed course was influenced by student background variables (e.g. gender). This study built on Hall's original study to explore the dimensions of gender and epistemologies in how students experience the reformed-content, traditional-pedagogy biology classroom.

While Hall conducted her study over nine semesters, I focused on data collected by Hall during the three semesters of pre-test and post-test MBEX I data for students who participated in the traditional classroom for the quantitative component of the design. I obtained permission to conduct this secondary analysis from the original researcher and the University of Maryland's Institutional Review Board.

The quantitative data provide a statistical description of students' epistemological beliefs and any change that occurred during the semester in relation to gender.

Research Questions

Through quantitative analysis, I explored the dimensions of gender and student epistemologies in a reformed-content, traditional-pedagogy organismal biology course and addressed the following research questions:

1- What is the relationship between gender and student epistemologies prior to instruction in a reformed-content, traditional-pedagogy organismal biology course?

2- What is the relationship between gender and student epistemologies after one semester of instruction in a reformed-content, traditional-pedagogy organismal biology course?

3- What are the gender differences in the change of student epistemologies from pre-test to post-test in a reformed-content, traditional-pedagogy organismal biology course?

I addressed the research questions using quantitative analysis of MBEX I data.

The Reformed-content, Traditional Pedagogy Organismal Biology Course

To meet the needs of the future STEM workforce, policy makers have called for reform of undergraduate biology courses to include more physics and math. In alignment with policy-maker recommendations, physics and biology faculty members at a large research university collaborated to develop courses with more interdisciplinary content. One of the courses developed was a traditional organismal biology course, a third semester course for biology majors at the university. The university's online course catalog described the course as, "The diversity, structure and function of organisms as understood from the perspective of their common physicochemical principles and unique evolutionary histories." Prior to enrollment in this course, students were required to complete two introductory courses or demonstrate competency in chemistry, cell and molecular biology, and ecology and evolution.

According to Watkins, Coffey, Redish, and Cooke (2012), the reformed-content, traditional-pedagogy organismal biology course was designed to "teach general guiding principles of biology that can be used to understand the differences and commonalities among organisms," and to "weave in mathematics, physics, and chemistry as part of an organizing framework to understand organismal diversity" (p. 010112-6). The course met for fifty minutes, three times per week in a large lecture hall. Students registered themselves for the course through customary registration procedures. Faculty made explicit the connections between biology, math, physics, and chemistry during lectures. With the content reform, faculty hoped to deepen students' understanding of organismal biology and help students develop a more sophisticated epistemology about biology as a field of scientific study.

Methods

This study used a pre-test/post-test design to analyze secondary data, including a quantitative analysis of MBEX I data collected as part of Hall's (2013) study. To assess student expectations for learning in the biological sciences classroom, Hall (2013) created a 32-question survey instrument to explore how student epistemologies in the traditional organismal biology course changed over time. The instrument used questions developed specifically for learning in the biological sciences (Hall, 2013) and was adapted from a similar survey that focused on student expectations for learning in physics. On most of the questions, students indicated agreement or disagreement with a statement on a five-point Likert scale ranging from 1 equaling strongly disagree to 5 equaling strongly agree. The MBEX I survey was validated via science experts, pilot studies, classroom observations, and student validation interviews. The survey took students less than thirty minutes to complete, and pre-test values on the survey were stable across the nine semesters that it was used.

The MBEX I explored four categories of student epistemologies for learning in the biology classroom. Hall (2013) described these four categories as “clusters” (p. 94). They included: *Facts versus Principles*; *Authority versus Independence*; *Isolated versus Connected; and Silo-maintenance versus Interdisciplinary Perspectives*. Like other epistemological questionnaires, the MBEX I instrument facilitated exploration of epistemologies along a continuum from naïve to expert. Hall suggested that there can be some overlap of these four clusters because the items used for each subscale are not orthogonal.

The *Facts versus Principles* cluster explored “whether biology needs to be considered as a connected, consistent framework or biology can be treated as unrelated facts” (Hall, 2013, p. 94). Students with naïve approaches to biology tended to view biology as a large set of facts but failed to see how these facts connected to larger principles and societal applications. These students tended to have a shallow learning approach, memorized facts, and failed to construct knowledge actively. Students with a more sophisticated view in this cluster saw biology as being composed of broader principles that needed to be understood, particularly though their application.

The *Authority versus Independence* cluster explored students' view of knowledge construction in the biological sciences. Students on the more expert side of this cluster viewed knowledge from the constructivist viewpoint, where the student actively constructs knowledge. Less sophisticated students viewed knowledge development as involving the transfer of facts from the authority figure to the student.

The *Isolated versus Connected* cluster explored student beliefs about biology knowledge as being connected to real word phenomena and future uses or as being isolated with little relationship to real world applications. Students with a sophisticated viewpoint in this category viewed biological sciences content as being connected to the real world, while unsophisticated students viewed it as being unrelated and independent of experience.

The *Silo-maintenance versus Interdisciplinary Perspectives* cluster explored student views of the multi-disciplinary nature of biology. The more sophisticated students in this category found the incorporation of other disciplines, such as physics and chemistry, in the biology courses meaningful and relevant to their learning. Students with a naïve view adhered to the "traditionally held conceptual boundaries in the disciplines" (Hall, 2013, p. 95).

During week one of the experimental period, the students were asked to complete a web-based MBEX I via their course's Blackboard site. Only students who voluntarily completed this pre-test were included in the data analysis. Neither the pre-test nor post-test measures impacted a student's course grade. At the end of the semester, students completed the post-test MBEX I housed on their course Blackboard site.

The quantitative analysis drew from three semesters of pre-test/post-test data from Hall's (2013) study which yielded a dataset of 316 students (201 women /115 men). The data set included only those students who completed both the pre-test and the post-test. I used SPSS (IBM SPSS Statistics for Windows, Version 23.0) to analyze the data and used descriptive statistics and inferential statistics to explore these data. To assess the reliability of each epistemological subscale, I calculated its Cronbach alpha, a measure of internal consistency for items that comprise a scale of subscale (Tavakol & Dennick, 2011). I used independent t-tests to examine potential gender differences in pre-test and post-test scores for each subscale. To explore possible changes in student epistemologies from pre-test to post-test, I used Repeated Measures Analysis of Variance (RM-ANOVA). For all tests in this study, I set alpha at 0.05.

Results

In this section, I discuss the results of the quantitative statistical analysis. These analyses explored the relationship between student epistemologies about science (dependent variable) and gender (independent variable) for students who participated in a reformed-content, traditional-pedagogy organismal biology course.

In the sections that follow, I describe the sample of students who participated in the study. I then present the results of the analyses for the first two research questions (i.e., whether there were gender differences in pre-test and post-test scores for each epistemological cluster), followed by the third research question (i.e., whether there were gender differences in any changes in epistemological understanding between the pre-test and post-test scores.

Sample

The sample characteristics of the students in the data set are summarized in Table 1, which provides information about the gender and grade breakdown of students who participated in the study. Nearly two thirds of the students were women. Roughly four fifths of students were either first-year students or sophomores, and there was no appreciable difference between men and women in grade standing.

Table 1 Sample

N (%)	Men (36%)	Women (64%)
First-year student	44 (38%)	78 (39%)
Sophomore	48 (42%)	89 (44%)
Junior	17 (15%)	21 (10%)
Senior	7 (6%)	13 (6%)
TOTAL	115 (100%)	201 (100%)

Gender Differences in Pre-test and Post-test Scores

The research questions, “What is the relationship between gender and student epistemologies prior to instruction in a reformed-content, traditional-pedagogy organismal biology course?” and “What is the relationship between gender and student epistemologies after one semester of instruction in a reformed-content, traditional-pedagogy organismal biology course?” were addressed using independent t-tests in IBM SPSS®. I explored the relationship between gender and level of sophistication of the students’ epistemological stance at pre-test and post-test for each of the four epistemological clusters (*Facts versus Principles, Authority versus Independence, Isolated versus Connected, and Silo-Maintenance versus*

Independence). The independent t-test allowed for efficient analysis when exploring the difference between two nominal variables (men and women) with one continuous measurement variable (mean on pre-test MBEX I and mean on post-test MBEX I)

Facts versus Principles. The *Facts versus Principles* subscale consisted of eleven MBEX I questions. I found the pre-test subscale ($\alpha = .61$) and post-test subscale ($\alpha = .74$) to be reasonably reliable for the purposes of this study.[5] Each question had a possible mean score range of 1 to 5, with 1 being the least favorable (e.g., biology consists of facts to be memorized) and 5 being the most favorable (e.g., biological knowledge is grounded in principles).

Table 2 presents the results of the independent t-test for the Facts versus Principles scores. The first two rows provide the results for gender differences by pre-test scores, while the second two rows provide the results for gender differences by post-test scores. As outlined in Table 2, men (M = 2.57, SD = .49) and women (M = 2.57, SD = .44) did not statistically differ on levels of epistemological sophistication at pre-test, t (314) =.13, p = .89. At post-test, there was also no evidence of differences, t (314) = -1.67, p = .87) between men (M = 2.64, SD = .56) and women (M = 2.66, SD = .60). The effect size for the pre-test analysis (d = .00) and the effect size for the post-test analysis are consistent with a "no difference" conclusion for these results. Both effect sizes are substantially below Cohen's (1988) convention for a small effect (d = .20). Both men (.07) and women (.09) made slight gains in their level of sophistication related to this epistemological cluster. However, the

[5] Cronbach's alpha is a measure of internal consistency of items used in a scale. While higher values are thought to reflect greater reliability, scales with alphas as low as .50 have been found to still be a valid and useful measure of an underlying construct (Schmitt, 1966).

independent t-test does not examine whether these differences are statistically significant (see the results of the repeated measures analysis of variance for statistical significance).

Table 2 Results of t-tests and Descriptive Statistics for Facts versus Principles by Gender

	Gender				
	Men N= 115	Women N = 201	95% CI for Mean Difference	*T*	*df*
Pretest	2.57 (.49)	2.57 (.44)	.09, .11	.13	314
Posttest	2.64 (.56)	2.66 (.60)	.14, .12	-.17	314

Note. * = $p < .05$, *** = $p < .001$. Standard Deviations appear in parentheses below means.

There were no statistically significant differences in scores between men and women at the beginning of the course, and no statistically significant differences between men and women in scores at the end of the course. Scores for both men and women shifted only slightly upward after one semester of instruction in the active learning environment.

Authority versus Independence**.** The *Authority versus Independence* subscale consisted of thirteen MBEX I questions. I found the pre-test (α = .62) subscale and post-test subscales (α = .61) to be, again, reasonably reliable for the purposes of this study. Each question had a possible mean score range of 1 to 5, with 1 being the least favorable (e.g., knowledge is acquired passively from an authority figure) and 5 being the most favorable (e.g., knowledge is constructed independently).

Table 3 presents the results of the independent t-tests for *Authority versus Independence* scores. The first two rows report the results for gender differences by pre-test scores and the second two rows report gender differences by post-test scores. As displayed in Table 3, men (*M* = 2.61, *SD* = .44) and women (*M* = 2.58, *SD* = .49) did not differ statistically on the pre-test scores. Nor did men (*M*= 2.62, *SD* = .41) and women (*M* = 2.56, *SD* = .49) differ statistically on the post-test score, *t* (270) = 1.03, *p* = .30. Both the effect size for the pre-test (*d* = .06) and post-test (*d* = .11) were below Cohen's (1988) convention for a small effect (*d* = .20), confirming that there was little to no difference between men and women in pre-test and post-test scores on the *Authority versus Independence* cluster. Scores for both men and women changed very little during the course (.01 for men and -.01 for women). There were no appreciable differences in scores between men and women at the beginning of the course, and no appreciable differences between men and women in scores at the end of the course. Scores remained roughly the same after one semester in the active learning environment.

Table 3 Results of t-tests and Descriptive Statistics for Authority versus Independence by Gender

	Gender				
	Men N=115	Women N =201	95% CI for Mean Difference	*T*	*df*
Pretest	2.61 (.44)	2.58 (.49)	-.07, .14	.66	314
Posttest	2.62 (.41)	2.57 (.49)	-.05, .16	1.03	270[6]

[6] Levene's Test for Equality of Variances was significant (*F* = 5.28, *p* = .02) for post-test scores indicating unequal variances. As a result, the degrees of freedom were adjusted from 314 to 270 to test for statistical significance.

Isolated versus Connected. The *Isolated versus Connected* cluster consisted of five MBEX I questions. Each question had a possible mean score range of 1 to 5, with1 being the least favorable (e.g., biological principles are isolated from real world phenomena) and 5 being the most favorable (e.g., biological principles are connected to the real world and future applications).The reliability scores for the pre-test (α = .56) and post-test subscales (α = .55) were the lowest for the subscales examined in this study, though still sufficient for the purposes of this study.

Table 4 provides the results for the independent t-tests for the *Isolated versus Connected* cluster. The table's organization is identical to the previous tables, with the first two rows reporting gender differences by pre-test scores and the second two rows reporting gender differences by post-test scores. Once again, men (M = 2.33, SD = .62) and women (M = 2.37, SD = .61) did not differ statistically on levels of epistemological sophistication at pre-test, $t(314)$ = -.48, p = .63, and men (M = 2.56, SD = .69) and women (M = 2.68, SD = .69) did not differ statistically on levels of epistemological sophistication at post-test, $t(314)$ = -1.51, p = .13. The effect size for the pre-test (d = .08) and post-test (d = .17) were less than Cohen's (1988) convention for a small effect (d = .20), suggesting there was little to no differences in scores between men and women at pre-test and post-test for the *Isolated versus Connected* cluster. Table 4, however, does indicate a potential gain in scores for men (.23) and women (.31) during the semester. There were no statistical differences in scores between men and women at the beginning of the course, and no statistical differences in scores between men and women at the end of the course. Scores for both men and women, however, did increase after one semester in the reformed-content, traditional-pedagogy environment.

Table 4 Results of t-tests and Descriptive Statistics for Isolated versus Connected by Gender

	Gender				
	Men N= 115	Women N = 201	95% CI for Mean Difference	T	df
Pretest	2.33 (.62)	2.37 (.61)	-.18, .11	-.48	314
Posttest	2.56 (.69)	2.68 (.69)	-.28, .04	-1.51	314

Note. * = $p < .05$, *** = $p < .001$. Standard Deviations appear in parentheses below means.

Silo-maintenance versus Interdisciplinary Perspectives. The *Silo-maintenance versus Interdisciplinary Perspectives* cluster consisted of nine items. I found the pre-test (α = .79) and post-test subscales (α = .66) to be reliable, particularly the pre-test score, for the purposes of the study. Each question had a possible mean score range of 1 to 5, with 1 being the least favorable (e.g., biology knowledge is isolated from other disciplines) and 5 being the most favorable (e.g., biology is connected to other disciplines).

Table 5 reports the results of the independent t-tests. The first two rows report the results for gender differences by pre-test scores; whereas, the second two rows report results for gender differences by post-test scores. As outlined in Table 5, men (M = 2.59, SD = .70) and women (M = 2.74, SD = .62) did not differ statistically on levels of epistemological sophistication at pre-test, t (314) = -1.95, p = .05, though the difference was nearly statistically significant. There was also no statistically significant difference, t (314) = 1.03, p = .30, between men (M = 2.56, SD = .57) and women (M = 2.63, SD = .52) at post-test. The effect size for the pre-test scores (d = .23) suggested a small difference between men and women at the beginning of the course, using Cohen's (1988) convention (d = .20), while the post-test effect size (d = .13) fell below this convention. Scores for men and women declined between the pre-test and post-test (-.03 for men and -.11 for women).

Table 5 Results of t-tests and Descriptive Statistics for the Silo-maintenance versus Interdisciplinary Perspectives by Gender

	Gender				
	Men N= 115	Women N = 201	95% CI for Mean Difference	*T*	*df*
Pretest	2.59 (.70)	2.74 (.62)	-.30, .00	-1.95	314
Posttest	2.56 (.57)	2.63 (.52)	-.19, .05	-1.16	314

Note. * = $p < .05$, *** = $p < .001$. Standard Deviations appear in parentheses below means.

There were no statistical differences in scores between men and women at the beginning of the course, and no statistical differences between men and women in scores at the end of the course.

Gender Differences in Epistemological Shifts

To address the research question, "What are the gender differences in the change of student epistemologies from pre-test to post-test in a reformed-content, traditional-pedagogy organismal biology course?" I conducted an RM-ANOVA in IBM SPSS®. I explored the interaction of gender with time on the mean student epistemological stance from pre-test to post-test and conducted this analysis for each of the four epistemological clusters. RM-ANOVA offers a robust method to compare mean scores where the dependent variable is continuous and the independent variables (gender and time) are categorical. For this analysis, time (pre-test and post-test) was coded as the within-subjects factor and the independent variable, gender (male and female) was assigned to the between-subjects factor. This allowed me to explore and interpret any statistical differences in subscale scores across time for all participants and any statistical gender differences across time for men and women (i.e., was the change in scores for men different than the change in scores for women).

Facts versus Principles. In the *Facts versus Principles* cluster there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality ($p < .05$). Both the variances ($p > .05$) and covariances ($p > .05$) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). These results indicated that the data met the assumptions for conducting an RM-ANOVA.

Table 6 reports the results. The first row reports the results for all students (main effect) while the second row compares results for men and women (interaction effect). As reported in Table 6, there was a statistically significant main effect of time, F (1, 314) = 4.94, p = .03, n^2 = .09, but there was no statistically significant interaction between time and gender for the *Facts versus Principles* cluster, F *(1, 314)* = 0.068, p = 0.80, n^2 = .00.

Table 6 Repeated Measures Analysis of Variance for Facts versus Principles Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	.929	1	4.94	.027
Time X Gender	.013	1	.068	.795
Error	.118	314		

Note. * = *p* < .05, *** = *p* < .001.

The significant difference in time for *Facts versus Principles* from pre-test to post-test indicated that both men and women became more sophisticated in their understanding of biology as being composed of broader principles rather than isolated facts after one semester of instruction in the reformed course. As indicated in Figure 1, the slopes for both men and women increased. Although the slope for women appears to be steeper than the slope for men, the difference in slopes is not statistically significant.

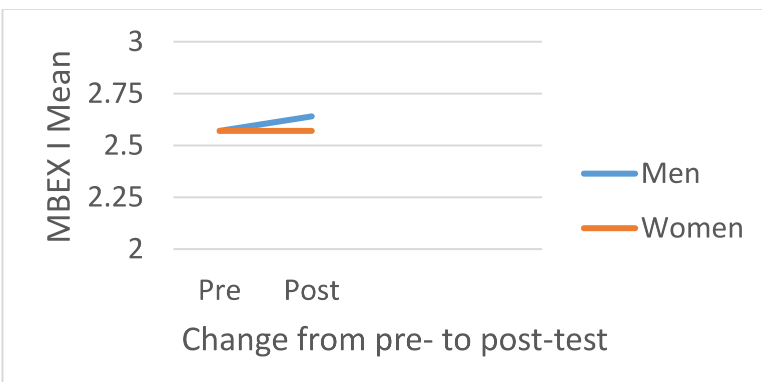


Figure 1. Results of Gender Difference MBEX I Mean Scores Over Time for the Facts versus Principles Cluster.

Authority versus Independence. In the *Authority versus Independence* cluster there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality (p < .05). Both the variances (p > .05) and covariances (p > .05) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). As with the *Facts versus Principles* cluster, these results indicated that the data met the assumptions for conducting an RM-ANOVA.

Table 7 reports the results of the RM-ANOVA for the *Authority versus Independence* cluster. Again, the first row, reports whether there is a change in scores for all students between the pre-test and post-test, while the second row reports whether the change in scores during this period was the same for men and women. As outlined in Table 7, there was no statistical difference in the main effect for the *Authority versus Independence* cluster, F (1,314) =.00, p = 1.00, n^2 = .00, and, once again, there was also no statistically significant interaction between time and gender for *Authority versus Independence* cluster, F (1, 314) =.10, p =.76, n^2 = .00.

Table 7 Repeated Measures Analysis of Variance for the Authority versus Independence Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	.00	1	.00	1.00
Time X Gender	.01	1	.10	.76
Error	.12	314		

Note. * = p < .05, *** = p < .001.

This result suggested that the slopes for both men and women were flat and showed little to no epistemological growth from pre-test to post-test in this cluster for men, and there was a slight degradation in epistemology for women as shown in *Figure 2*.

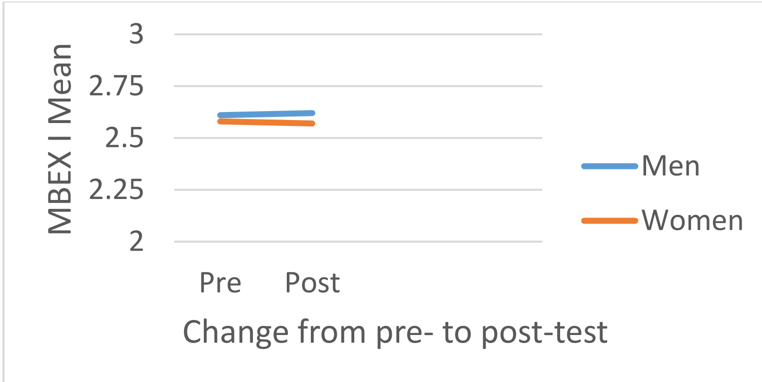


Figure 2. Results of Gender Difference MBEX I Mean Scores Over Time for the Authority versus Independence Cluster.

Isolated versus Connected. In the *Isolated versus Connected* cluster there were no outliers as assessed by box plot distributions and the data were distributed normally as assessed by Shapiro-Wilk's test of normality ($p < .05$). Both the variances ($p > .05$) and covariances ($p > .05$) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). As these results indicate, the data satisfied the assumptions of RM-ANOVA.

Table 8 provides the results for the RM-ANOVA for the *Isolated versus Connected* cluster, with the first row reporting the main effects of time and the second row reporting whether the effects of time differed by gender. As demonstrated in Table 8, there was a statistically significant difference in time for men and women from pre-test to post-test, F (1, 314) = 40.57, p <.01, n^2 = .11, but no statistically significant interaction between time and gender, F (1, 314) =1.02, p =.31, n^2 = .00. In other words, the course was successful at developing more sophisticated epistemological understandings of biological principles as connected to real world phenomena and future applications for both men and women in the study.

Table 8 Repeated Measures Analysis of Variance for the Isolated versus Connected Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	10.85	1	40.57	.00
Time X Gender	.27	1	1.02	.314
Error	.27	314		

Note. * = *p* < .05, *** = *p* < .001.

As demonstrated by Figure 3, the direction of change indicated that both men and women became more sophisticated in their viewpoint of biology's relationship to the broader world after one semester of instruction in the course. While the slope for women is greater than the slope for men, the difference in the slopes is not statistically significant.

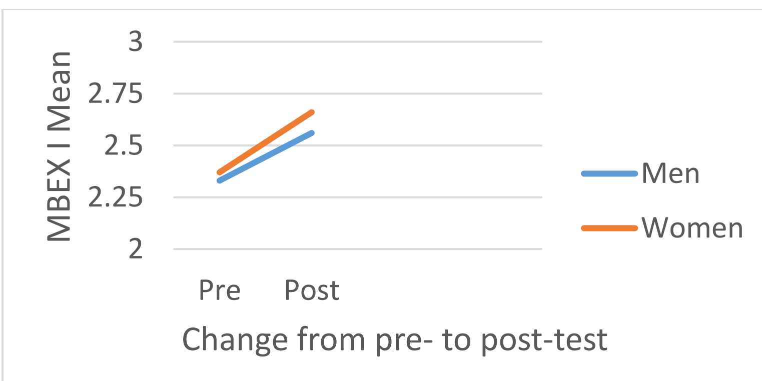


Figure 3. Results of Gender Difference in MBEX I Mean Scores Over Time for the Isolated versus Connected Cluster.

Silo-maintenance versus Interdisciplinary Perspectives. In the *Silo-maintenance versus Interdisciplinary Perspectives* cluster there were no outliers as assessed by box plot distributions, and the data were distributed normally as assessed by Shapiro-Wilk's test of normality ($p < .05$). Both the variances ($p > .05$) and covariances ($p > .05$) were homogenous on Levene's Test of Homogeneity of Variance and box plots respectively. Mauchly's Test of Sphericity indicated that the assumption of sphericity was met for the two-way interaction, X^2 (2) = .00, p <.05). As with the other clusters, the data for the *Silo-maintenance versus Interdisciplinary Perspectives* cluster satisfied the assumptions for conducting an RM-ANOVA.

Table 9 reports the results for these analyses. The first row reports the results for the main effect of time and the second row reports the results for the effect of gender by time. As indicated by Table 9, there was no statistical difference by time in the scores of men and women, F (1, 314) = 3.60, p = 0.06, n^2 = .01, or statistical difference for the interaction by time and gender, F (1, 314) = 1.02, p = 0.31, n^2 = .00 for this cluster. There was no significant change between the pre-test and the post-test in students' beliefs about whether biology was a distinct discipline or connected to other disciplines.

Table 9 Repeated Measures Analysis of Variance for the Silo-maintenance versus Interdisciplinary Cluster

Effect	*MS*	*Df*	*F*	*p*
Time	.72	1	3.60	.06
Time X Gender	.20	1	1.02	.313
Error	.20	314		

Note. * = p < .05, *** = p < .001.

These results suggested that despite intentional instruction designed to teach students to relate biological concepts to principles from other scientific disciplines, both men and women experienced a near significant (p = .06) decline in epistemological sophistication after one semester of instruction as demonstrated in Figure 4.

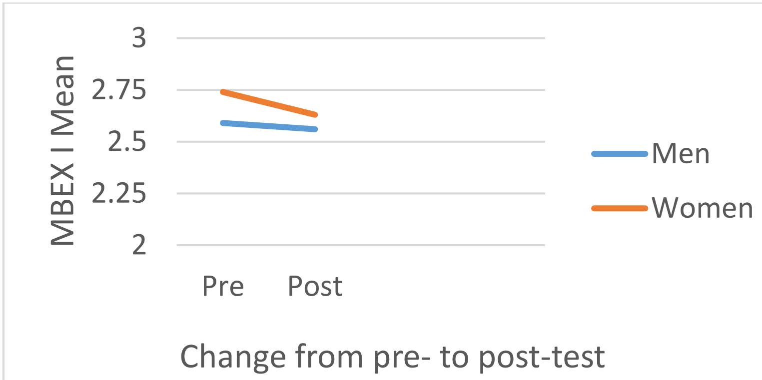


Figure 4. Results of Gender Difference in MBEX I Mean Scores Over Time for the Silo-maintenance versus Interdisciplinary Cluster.

Conclusion

The quantitative results indicated there were no significant differences between women's and men's MBEX I scores at pre-test or post-test in any of the four epistemological clusters. However, both men and women demonstrated significant positive shifts in the *Facts versus Principles* (p =.03) and *Isolated versus Connected* (p =.00) clusters after one semester of instruction in the reformed-content, traditional-pedagogy course. This result demonstrated that the inclusion of reformed content in the course was successful in shifting students toward a more sophisticated epistemological stance that biological science knowledge is based on principles rather than consisting of isolated facts and that biology consists of connected principles with real world relevance.

There were no significant epistemological shifts in the *Authority versus. Independence* cluster, but the epistemology for men increased slightly, while the women's epistemology degraded slightly. While not statistically significant, it is interesting to note that women became more aligned with the naïve epistemology that knowledge is received from an authority figure. I expected this result in this category given that traditional lecture environments have been criticized for similar outcomes. Both women and men demonstrated an almost significant (p=.06) decline in the *Silo maintenance versus Interdisciplinary Perspectives* cluster. This result may suggest a resistance to the inclusion of math and chemistry in the biological sciences course content for both men and women.

Appendix B: MBEX I

1. Biology courses should focus on biological subjects and should not present much chemistry and/or physics.
   1- Strongly Disagree
   2- Disagree
   3- Neutral
   4- Agree
   5- Strongly Agree

2. All I need to do to understand most of the material in a biology class is to memorize the basic facts, read the textbook, and/or play close attention in class.
   1- Strongly Disagree
   2- Disagree
   3- Neutral
   4- Agree
   5- Strongly Agree

3. Knowledge in biology consists of many unrelated facts.
   1- Strongly Disagree
   2- Disagree
   3- Neutral
   4- Agree
   5- Strongly Agree

4. I believe it is possible to get a "C" or better in this course without understanding the course topics very well.
   1- Strongly Disagree
   2- Disagree
   3- Neutral
   4- Agree
   5- Strongly Agree

5. If biology professors gave really clear lectures, then most good students could learn the material without having to spend a lot of time thinking outside of class.
   1- Strongly Disagree
   2- Disagree
   3- Neutral
   4- Agree
   5- Strongly Agree

6. I am more interested in general biological principles than the specific facts that demonstrate those principles.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

7. The knowledge of evolutionary processes is relatively unimportant for understanding human biology.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

8. Using mathematics to explain biological phenomena is more confusing than helpful to students.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

9. The knowledge that I acquired in this biology class is directly applicable to important issues currently facing the world.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

10. When studying for a biology exam, the key thing is knowing all the facts about the topics to be covered on the exam. Understanding the big ideas might be helpful for some essay questions, but not for most of the exam.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

11. Studying the simple organisms in this class, like sea urchins, jellyfish, and snails, tells me very little about how human systems work.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

12. Even if this class were not a requirement for my major, I would still take it.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

13. Learning biology requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

14. Although math in biology provides another way of describing biological phenomena, it does not really help provide a deeper understanding.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

15. I don't need to be good at math to be good at biology.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

16. Biology classes should be designed to help the students master the factual material for doing well on the MCATs, GREs, and other professional exams.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

17. This biology class gives me knowledge and skills to think critically about biological topics in current events.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

18. Learning biology is mostly a matter of acquiring the factual knowledge presented in class and/or in the textbook.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

19. I don't need to be good at physics to be good at biology.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

20. Biology class should just present all the different facts. Trying to present the unifying theories doesn't really help us understand anything.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

21. I find that I often forget the material I've learned for a biology test soon after the exam.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

22. I don't need to be good at chemistry to be good at biology.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree

5- Strongly Agree

23. Memorizing all of my lecture notes in this class verbatim is all I need to do to get an "A" in this course.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

24. We use this statement to discard the survey of people who are not reading the questions. Please select agree - option 4 - for this question to preserve your answers. (do not mark option 5)
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

25. The benefits of learning to be proficient using math and physics in biology are worth the extra effort.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

26. Physics is relatively unimportant for understanding most biological processes.
1- Strongly Disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly Agree

27. I expect my exam performance in biology courses to reflect how well I can:
A. recall course materials the way they are presented in class.
B. apply course materials in situations not discussed in class.

28. Justin and Dave are studying together for an upcoming test and discussing the best way for them to study. Justin: When I'm learning biology concepts for a test, I like to put things in my own words, so that they make sense to me. Dave: But putting things in your own words doesn't help you do well in the class. The textbook and lectures were written by people who know biology really well. You should learn things the way the textbook and lectures present them.
A. Justin's study method is most effective.

B. Dave's study method is most effective.

29. Brandon and Jamal are discussing how a good biology textbook should be organized. Brandon: A good biology textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each chapter as separate because they're not really separate. Jamal: But most of the time, each chapter is about a different topic and those topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

A. Brandon's textbook organization is best.
B. Jamal's textbook organization is best.

30. Of the following test formats, which is best for measuring how well students understand the material in biology?

A. A large collection of short-answer or multiple-choice questions, each of which covers one specific fact or concept.
B. A small number of longer questions and problems, each of which covers several facts and concepts.

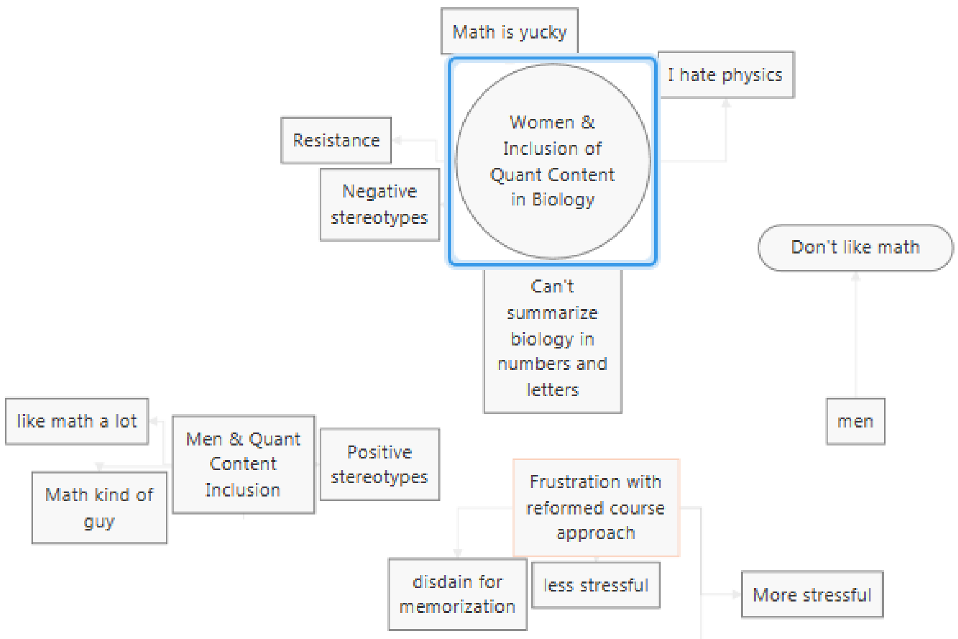
31. Samantha and London are studying for an upcoming test on evolution.
Samantha: In order to do well on this test, I'm just going to concentrate on understanding the few underlying principles, which I will be able to apply to different situations.
London: I don't think understanding the principles tells you enough about every situation, I think I'm going to focus on memorizing as many different ways that organisms have evolved as I can.

A. It is best to study like Samantha.
B. It is best to study like London.

32. Biology and physics are:

A. related to each other by common principles.
B. are separate and independent of each other.

Appendix C: Concept Map



Appendix D: MBEX Questions Sub-scales by Cluster

Cluster	**MBEX Questions Subscales**
Facts versus Principles	3, 6, 10, 11, 18, 20, 27, 28, 30, 31, 32
Authority versus Independence	2, 4, 5, 13, 18, 21, 23, 27, 28, 29, 30, 31, 32
Isolated versus Connected	7, 9, 11, 16, 17
Silo-maintenance versus interdisciplinary perspectives	1, 8, 14, 15, 19, 22, 25, 26, 32

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